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1. Your reference — X436

2. Patent application number *(The Patent Office will fill in this part)* — 0229655.6 — 20 DEC 2002

3. Full name, address and postcode of the or of each applicant *(underline all surnames)* — XAAR TECHNOLOGY LIMITED, UNIT 316, SCIENCE PARK, CAMBRIDGE, UK, CB4 0XR

   Patents ADP number *(if you know it)* — 08531626001

   If the applicant is a corporate body, give the country/state of its incorporation — UK

4. Title of the invention — DROPLET DEPOSITION APPARATUS

5. Name of your agent *(if you have one)*

   "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)* — ~~MR NICK ROBERTS~~ ~~XAAR TECHNOLOGY LIMITED~~ ~~SCIENCE PARK~~ ~~CAMBRIDGE~~ ~~CB4 0XR~~

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   WC1X 8AL.

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

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Droplet Deposition Apparatus

The present invention relates to droplet deposition apparatus and in particular drop on demand ink jet printers and their manufacture.

Drop on demand inkjet printers typically fall under one of two broad categories: bubble-jet or mechanical. Bubble-jet printers eject a drop by selectively heating a fluid and generating a bubble that provides sufficient force to eject a droplet. Mechanical printers eject a drop by varying the volume of a chamber to apply pressure to the fluid in the chamber and thus eject a drop. The present invention is primarily concerned with mechanical drop on demand ink jet printers and in particular mechanical printers using a piezoelectric material. Consequentially bubble jet devices will not be discussed in any greater detail.

The piezoelectric material conventionally utilised in ink jet printing is a lead zirconate titanate (PZT) ceramic material. PZT is relatively fragile and is manufactured as sheets of a sintered material. The raw sheets of material are machined either mechanically or through some other process to form individual actuators.

One particularly elegant form of an actuator is one produced by the applicant under the product code XJ500. Channels are sawn into the piezoelectric material such that they are bounded on either side by a wall. A cover plate is provided to close the top surface of the channels and a nozzle plate is attached to the open front of the channel. Nozzles are formed extending through the nozzle plate and communicate with the channels. Electrical voltages applied across the walls cause the walls to deflect in shear. The deflection pressurises ink in the channel and causes a droplet to be ejected through the nozzle.

It has been proposed that it may be possible to mould a piezoelectric print head and certain structures are proposed. One structure is proposed in WO 00/16981

relating to a circular chamber having a lower wall of piezoelectric material formed by moulding.

Whilst forming an actuator by moulding is quick some accuracy is lost over the traditional mechanical sawing methods. In particular, the piezoelectric material shrinks on firing often up to 30%. This shrinkage is not uniform across the piezoelectric material and this leads to actuators having different channel spacings along the length of the array.

The present invention seeks to address this and other problems.

According to one aspect of the present invention there is provided an actuator component for a drop on demand ink jet printer, said component comprising a body having a top surface, an opening in said top surface extending into said body, an actuator structure located substantially within in said opening and electrode means; said electrode means being disposed so as to be able to apply a field to said actuator structure so as to cause said actuator structure to deform.

In a preferred embodiment the body does not significantly alter its dimensions when exposed to extremes of heat. It is preferred that the coefficient of thermal expansion (TCE) of the body is similar to that of the actuator and in the case of piezoelectric or magnetostrictive material the particularly preferred materials are silicon or alumina. Other appropriate materials may be found by routine experimentation. Where the material is silicon the aperture may be formed by reactive ion etching (RIE) or deep reactive ion etching (DRIE). Other techniques such as laser cutting or machining will also be appropriate if the material is alumina.

It is preferred that the actuator structures are isolated actuator structures i.e. each structure is separate and distinct from adjacent actuator structures.

However, provided that the thickness of that layer does not enable a self-supporting sheet of actuator structures to be formed, the actuator structures may be connected by a thin layer of material having the same properties as the actuator structures and, in this case, the actuator structures would still be considered to be isolated.

The opening extending into the body from the top surface may have sides that are perpendicular to the top surface. Alternately, the surfaces of the opening may lie at a non perpendicular angle to the top surface i.e. the opening may taper inwards or outwards as it extends from the top surface.

The shape of the opening may be used to define the shape of the actuator element or additional mould elements may be formed in the opening to define the actuator shape that is preferably generally convex or follows the outline of a frustum.

Preferably at least a part of the body and mould portions that define the actuator shape are removed once the actuator has been formed to enable a freer movement of the actuator though the actuator may remain attached to at least a portion of the body. The removal of this material may be performed by etching or some other technique from the surface of the body opposite the top surface. The opening may then extend through the body with the actuator structure defining an impermeable barrier across it.

The opening may be circular but more preferably is elongate in shape. A number of openings may be provided through the body in either a linear array or matrix arrangement.

The electrodes that are disposed so as to be able to apply a field across the actuator may be formed for example of aluminium or nickel. It is preferred that one of the electrodes constitutes a ground electrode and the other provides the

active electrode and it is preferred that they extend over opposite surfaces of the piezoelectric structure.

A diaphragm may be provided that extends over one or both surfaces of the body. The actuator structure may act on said diaphragm thereby deflecting at least portions of it away from the respective surface. Where a cover plate is attached to the body thereby defining an ejection chamber the actuator should be arranged so as to effect a pressure disturbance on fluid contained within the ejection chamber. The diaphragm can provide both a uniform wall for the base of the chamber as well as protection for the actuator against chemical attack from the ink.

As an alternative to the diaphragm any space between the actuator structure, the opening and the plane of the top or bottom surface may be filled by a compressible material such as, for example, silicon rubber.

The material of the cover plate is preferably matched to the body in terms of its coefficient of thermal expansion and the shape of each chamber is preferably matched to the shape of the openings i.e. where the opening is elongate the channel is elongate.

According to a second aspect of the present invention there is provided a component for ejecting a droplet in a direction of droplet flight, said component comprising an actuator structure displaceable by actuation in the direction of said droplet flight; said actuator defining in part an ejection chamber and comprising a port through which said droplet is ejected.

In the preferred embodiment the actuator structure defines at least three walls of the ejection chamber. The chamber is preferably generally convex or follows the outline of a frustum with the port being provided in the base. The actuator is displaced in the direction of ejection flight thereby ejecting a drop.

The actuator may be located within an opening provided in a base structure or mounted to a top surface. Ink may be supplied to the chamber from either end with the top surface of the base structure closing the chamber or through openings formed in the base structure.

A nozzle plate with nozzles may be applied to a surface of the actuator structure such that the nozzles are in fluid communication with the ports.

The actuator structures are preferably non-planar and form relatively complex three-dimensional shapes that are generally convex or follow the outline of a frustum.

According to a third aspect of the present invention there is provided a component for a drop on demand ink jet printer, said component comprising a body having a plurality of openings extending into said body, actuator structures located substantially within each opening wherein said actuator structure is formed by a process of electrophoresis

According to a fourth aspect of the present invention there is provided a component for a drop on demand ink jet printer, said component comprising a body having a plurality of openings extending into said body, actuator structures located substantially within each opening wherein said actuator structure is formed by a process of sputtering.

In an alternative embodiment the piezoelectric structure is formed from a slurry of piezoelectric particles in a disposable matrix which typically a thermoplastic material though other materials, including thermosetting materials such as epoxy, will suit.

The aperture is etched through the body and a sacrificial mould element

provided within the aperture. This is used, with the body to form a piezoelectric structure by the known technique of ceramic injection moulding. The body is then subjected to a high temperature so as to sinter the piezoelectric material. Where the sacrificial mould element is a polymeric material this is burned out and removed during the sintering step.

In a particularly elegant form of this method the sacrificial mould element is part of the body. Reactive ion etching forms a tapered aperture that may be used as the mould. After the sintering step the body may be etched from the opposite side to release the piezoelectric structure. Since RIE is a selective process the silicon can be removed without removing the piezoelectric structure.

This elegant technique may similarly be used where piezoelectric material is deposited as thin layers either singly or as multiple layers. The layers may be deposited either by sputter coating or as the thin flexible layers described above.

According to a fifth aspect of the present invention there is provided a component for a drop on demand ink jet printer, said component comprising a body having a plurality of openings extending into said body, actuator structures located substantially within each opening wherein said actuator structure is formed by a process of vacuum forming.

In a preferred method the body of silicon is reactive ion etched to form the aperture. The piezoelectric material is provided in the form of a flexible sheet that is laid against one side of the planar body. The sheet is subsequently subjected to a pressure difference between the aperture and the opposite side of the sheet with the lower pressure being located within the aperture.

The flexible sheet is thus moulded into a three dimensional structure and may be fired to sinter the piezoelectric particles in the flexible sheet and burn out the matrix carrier. Electrodes are deposited on the inner and outer surfaces of the

formed piezoelectric structure. A diaphragm and / or polymeric material may be deposited to insulate the electrode material from the ink.

According to a sixth aspect of the present invention there is provided a method of forming a component for an ink jet print head comprising the steps a) providing a body having a mould feature, b) forming a deformable actuator structure, the shape of said actuator structure being defined, at least in part by said mould feature, c) removing at least a portion of said mould feature and d) providing electrode means; said electrode means being disposed so as to be able to apply a field to said actuator structure so as to cause said actuator structure to deform whilst said actuator structure is attached to said body.

The body provides support to the actuator both in manufacture and use and provides mould features for partly defining the shape. The actuator is preferably non planar and may be located within openings provided in the body.

According to a seventh aspect of the present invention there is provided a method of forming a component for an ink jet print head comprising the steps a) providing a body having a top surface, b) forming an opening in said top surface and extending into said body and; c) forming within said opening an actuator structure; said actuator structure remaining attached to said body during actuation.

According to an eighth aspect of the present invention there is provided a channelled component for a drop on demand ink jet printer comprising elongate channel walls defining a plurality of elongate liquid channels, each channel comprising one wall that is resiliently deformable in an actuation direction orthogonal to the channel length; a respective ejection nozzle connected with the channel at a point intermediate its length; a liquid supply providing for continuous flow of liquid along said channel; acoustic boundaries at respective opposite ends of the channel serving to reflect acoustic waves in the liquid of the

channel wherein the inter-channel spacing of said acoustic boundaries is different to the inter-channel spacing of said nozzles.

In a preferred embodiment the inter-channel spacing of said acoustic boundaries is less than that of the inter-channel spacing of said nozzles. The channels may be chevron shaped with the chevron angle becoming more acute with increasing distance from a channel that is substantially straight.

It is preferred that the substantially straight channel is central to the module and a reverse series of chevron shaped channels is arranged on the opposite side.

It is preferred that the channels are arranged on a tile with the array of nozzles extending linearly across said tile. A plurality of like tiles may be butted together along respective edges and wherein there is provided an array nozzles having an equal linear nozzle spacing across the width of the like tiles and across the butt joint.

The edges of the butt joint may be serrated with the respective serrations capable of being interleaved.

An actuator component with actuators having a similar shape to each of the different shaped channels may be laminated to the channelled component to form an ink jet print head.

According to an ninth aspect of a present invention there is provided a chamber component comprising a plurality of ejection chambers having different dimensions and containing an ejection fluid, an actuator component comprising a plurality of actuators having different dimensions, wherein said actuator component is joined to said chamber component such that an ejection chamber and an actuator are combined to enable the actuator to effect a pressure disturbance in said fluid in order to eject droplets from said chambers and

wherein said ejected droplets have substantially identical characteristics.

The invention will now be described by way of example only with reference to the following diagrams in which:

Figure 1a, b and c depict an inkjet component according to the present invention.

Figure 2a and b depict an alternative inkjet component according to the present invention.

Figure 3 depicts a channel arrangement on a module

Figure 4 depicts an alternative arrangement of channels in a module

Figure 5 depicts an arrangement when two modules are butted together

Figure 6 shows an alternative butting arrangement

Figure 7 is a diagram of butted modules with the channels rotated by 90o

Figure 8 is an alternative channel arrangement.

Figure 9 is a diagram of butted modules with chevron shaped channels

Figure 10 depicts an alternative butting arrangement for the modules comprising chevron shaped channels

Figure 11 shows an actuator component according to the present invention.

Figure 12 shows a print head incorporating the component of Figure 1

Figures 13a to 13d show a method of manufacturing a component according to one embodiment.

Figures 14a to 14c depict a further method of manufacturing the component

Figures 15a to 15al depict a method of manufacturing an actuator component

Figures 16a to 16c similarly depict a further method of manufacturing the component

Figures 17a to 17c show an alternative method of manufacture where a body acts as the mould and final support component.

Figure 18a and 18b are diagrams of an alternative actuator structure

Figure 19a and 19b are diagrams of an alternative actuator structure

Figure 20 depicts an alternative actuator structure.

In the Figures, like parts are accorded the same reference numerals.

Referring first to figures 1(a) and 1(b), where figure 1(b) is a sectional view taken across line X-X of figure 1(a), a single channel pulsed droplet print head consists of a cover component 14 and an actuator component 1, with an ejection chamber 12 defined between these components.

The cover component is formed of a nickel alloy, a material thermally matched to the material of the actuator component which is primarily silicon comprising an active portion 8. The ejection chamber is elongate and has an acoustic length AL defined by a distance between ink supply ports 3 formed through the actuator component.

The supply ports can both supply and remove ink from the ejection chamber depending on whether it is desired that there is a circulation of ejection fluid. Where there is circulation of ink a flow of the order ten times the maximum droplet ejection volume flowrate is desired. The size the ink supply ports are such that the pressure drop is not excessive. It is desired that the ports extend across the entire width of the channel or at least a substantial proportion of the channel.

In operation the active portion 8 disturbs the ejection fluid in the channel and initiates a pressure wave travelling longitudinally along the channel. The pressure waves are reflected at the acoustic boundaries adjacent the supply ports and converge at the nozzle to effect droplet ejection. The ejection fluid is disturbed by movement of the active portion of the actuator substrate either towards or away from the ejection chamber.

To generate a longitudinally travelling acoustic wave the movement of the actuator into the channel should be quick, less than AL/c where c is the speed of sound through the ejection fluid. Preferably the movement is at most half AL/c

and even more preferably an order of magnitude less than AL/c. The distance of the movement of the active portion into or away from the channel need not be great and sufficient ejection force may be generated by a travel into or away from the channel of below 50 µm.

By operating the active portion a number of times quickly in succession it is possible to increase the volume of a droplet of fluid ejected from the nozzle. Pulslets can be chosen that either eject an additional volume of ink whilst a droplet is still attached to a nozzle plate or eject an additional volume of ink that travels faster than a previously ejected droplet of ink and merges with said previously ejected droplet of ink prior to its arrival at the substrate. The technique to increase the volume of ink ejected is called greyscale and is described in greater detail in EP-A-0 422 870 (incorporated herein) and consequentially will not be described in greater detail.

The structure of Figure 1(a) and 1(b) may be modified to form what is known in the art as an "end shooter" and depicted in Figure 1(c). Similar cover and actuator components are formed except that the nozzle is provided at the end of the channel. This too operates by initiating an acoustic pressure wave that ejects a droplet from the nozzle.

An ejection channel typically has a length of 2mm or 1mm in the case of an end-shooter. A channel for a greyscale actuator is less than that for a binary actuator in order to allow the multiple drops to be ejected in the prescribed time period. For a binary acoustic print head channels of sizes of the order 1cm are suitable.

A further form of a channel pulsed droplet is shown with reference to Figure 2 (a) and (b). In this situation the active portion 8 of the actuator plate projects from the non-active support 1.

The acoustic length AL in this case is defined between the step changes at

either end of the active portion 8.

Figure 2b depicts the situation where three adjacent ejection chambers are formed, a group of chambers being formed as a module. A module is formed as a matrix of ejection channels as shown in Figure 3.

The module of figure 3 comprises 64 channels arranged as four rows of 16. Each row is individually capable of printing at a drop density of between 100dpi and 360 dpi and is offset from an adjacent row by 1/n where n is the total number of rows to allow a module printing density of n times the individual row printing density.

The module is formed as a parallelogram with the sides being angled at approximately 120o to the bottom surface. The channels are arranged such that their direction of longitudinal extension is perpendicular to the bottom surface.

In figure 4, the longitudinal direction of the channels is rotated by 90o such that it lies parallel to the bottom surface. The rows are angled to provide the same module drop density as provided in Figure 3, however, other angles are may by chosen to provide other drop densities and this angle need not be the same as the module angle.

The relationship between channel length, channel angle, module angle and desired dpi for both the horizontally and vertically orientated channels should be chosen to allow the modules to be butted together in a side by side relationship to build up a head that is wider than a single module with no noticeable variation in drop spacing across the entire width of the head. The relative distances between the nozzles define the drop spacing.

In an acoustic wave droplet generating device, where channel lengths tend to be greater than in an impedance droplet generating device, such butting can be

difficult due to the available wall thickness between the modules.

Figure 5 shows two modules 50a, 50b butted side by side and comprising the vertically arranged channels. The channel spacing is such that a constant drop density is achieved across each of the modules and across the butt joint.

Due to the length of the channels there are critical dimensions along the edges of the modules where there is very little material providing support to either the actuator or channelled components – the actuator component being laminated to the channelled component. Failure of the walls at these points can lead to an inoperative ejection chambers in the print head and hence the scrapping of the module.

The critical dimension can be increased by offsetting the modules as shown in Figure 6 where the second module is offset by a distance equal to half the module height. Each of the outer channels can be inset from the edges of their respective modules providing a more robust print head whilst maintaining a constant nozzle pitch across the width of the head.

By rotating the direction of the channels through 90o it is possible to transfer the critical dimension from the high-tolerance portion at the edges of the channels to the more tolerant portions at the ends of the channels as shown in Figure 7. The outer walls of the outer channels can therefore be made thicker without fear of damage. It is also possible to choose module and channel angles so that the outer channels need not be operate and may be used as dummy channels.

As mentioned earlier, the slant of the channels, the angle of the parallelogram and the length of the array all have an effect on the amount of area available for butting.

Figure 8 depicts a further arrangement of channels to allow for robust butting of

the modules. In all the previous figures the channels have been depicted as being straight. However, where the channels are formed by non-sawing means, such as etching or ablation they may be formed in alternative shapes and this is particularly suitable where the channels eject fluid using acoustic waves.

The channels of figure 8 are fanned outwards from the middle channel in increasingly acute "chevrons". A constant nozzle pitch can therefore be achieved albeit at a slightly lower pitch than if the channels were straight. The outer channels are longer than the inner channels and any obvious variations in ejection characteristics may be remedied by forming an acoustic reflection boundary modifier in either the channelled component or actuator component.

The actuators in the actuator component may similarly be shaped in a chevron form so as to correspond to the channels in the channelled component and to minimise any variations in the ejection characteristics.

An arrangement where two modules of the chevron shaped channels are butted is depicted with reference to Figure 9. Beneficially, the modules may be formed as a square or rectangular shaped tile. Unlike the situation where the channel runs parallel to the edge of the module and there is only a narrow, delicate wall defining the edge of the outer channel and module the proportion of the wall in this example of that thickness is relatively small.

In the structure of Figure 10, the edges of the modules are concertinaed and interleaved to provide additional support at the butting edges and a more robust join when filled with adhesive 51.

Turning now to the actuator component, a typical device according to the present invention is depicted in Figure 11.

A planar silicon body is provided that 2 has an elongate aperture formed within

it. Inside the aperture is formed a structure of a piezoelectric material 8.

An electrode material 7 is provided that extends over the top or outer surface of the piezoelectric structure and additionally extends over the top surface of the body and connects with adjacent piezoelectric structures located in the body.

A further electrode 6 is located on the inside or lower surface of the piezoelectric structure. This is separate from the other electrodes on the other piezoelectric structures and is used as the active electrode.

The piezoelectric material is polarised by applying a polarising field between the electrodes to polarise it in the direction depicted by the arrows. The polarised actuator structure thus formed can be caused to deflect to eject a droplet from an ejection chamber by applying a voltage between the electrodes.

The applied field causes the arms of the actuator structure to thin and elongate or thicken and shorten depending on the direction. This has the effect of moving the planar surface of the actuator structure out of the plane of the body component 2. The angle of the walls provides a gearing ratio that improves the ejection capabilities of the actuator.

As depicted in Figure 12, a diaphragm plate 10 can be attached to the body to separate the ink chamber 12 from the piezoelectric structure 6. A polymeric or rubber material 13 is supplied between the outer surface of the piezoelectric structure and the diaphragm 10 to add to the structural stability provided by the silicon body 2. The material should be relatively stiff to maintain the efficiency of the actuator. Silicon rubber has been found to be particularly appropriate. Where the silicon rubber is provided without the diaphragm plate it is possible to protect against chemical attack from the ink by applying a thin coating of parylene or some other passivant.

The cover plate 14 spans the opening and serves to define, with the body, the ejection chamber 12. Application of a voltage across the walls of the piezoelectric structure serves to deflect the diaphragm into the chamber thus instigate a pressure wave propagation that causes a droplet to be ejected from the nozzle 16.

Figure 13, a to d depicts a way of manufacturing a component according to the present invention. Firstly as in Figure 3a a silicon body 2 is provided that has an opening 4 formed therein.

Inserts 18 are provided that serve to assist the moulding process. These are a plastics material that will be removed after or during the forming of the piezoelectric structure.

A former 20 is provided within the aperture and is used to provide shape to the piezoelectric structure that is formed between it and the removable inserts. The piezoelectric slurry is injected into the cavity from ports (not shown) provided in the former. A plate 22 is provided to close the cavity. The removable inserts are sacrificial in that they may be destroyed during a subsequent processing step.

The piezoelectric slurry comprises piezoelectric particles suspended in a matrix of an epoxy material. The epoxy is allowed to harden in the cavity but the application of heat or, where it is a UV curable epoxy, through the use of UV light to provide the initial structure and then the former and plate are removed.

The body, piezoelectric structure and removable inserts are then heated to sinter the piezoelectric particles and burn-out the removable inserts. As the piezoelectric structure is supported by the silicon body there is no significant shrinkage across the length of the body, any shrinkage being small and predictable.

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An electrode material is deposited onto the inner and outer surfaces of the piezoelectric structure either by vacuum sputtering, electroless plating or some other known technique.

Figure 14, a to c depicts a further way of manufacturing the component of the present invention. In Figure 14a the silicon body is etched by reactive ion etching. This creates an aperture having a natural taper which may be exaggerated by any known technique.

The piezoelectric structure may be formed as above or by laying down multiple thin sheets of the piezoelectric material by vacuum forming and the like. After sintering the piezoelectric structure in Figure 14b the body is again etched, but this time from the opposite surface, to free the piezoelectric structure as shown in Figure 14c. Electrodes are again applied using a known technique.

Suitably, the components can be formed using MEMS, parallel processing techniques. Such a process is described in figure 15.

A silicon plate 100 is provided in Figure 15(a) to which a seed plate 102 is sputtered 15(b). A coating of silicon dioxide 104 is sputtered onto the plate and a layer of silicon nitride 106 deposited onto the uncoated surface of the silicon, 15 (c) and (d). A photoresist 108 is then applied to the layer of silicon nitride by a process of spin coating or the like 15(e).

A portion 110 of the photoresist 108 is masked and exposed as in 15(f) and subsequently developed thereby removing it (15g). The now exposed silicon nitride is etched to reveal the bare silicon 15(h) The remaining photoresist is then removed (15i).

A new layer of photoresist 112 is deposited and exposed 114 and developed as described earlier. The areas revealed by the developed photoresist are filled

with a metallic material 116 though a process of electroplating, pulsed electroplating and electrodeplating as depicted in figures 15(j), 15(k), 15(l) and 15(m).

The undeveloped photoresist 112 is removed 15(n) and a layer of Silicon Nitride 118 covered by a layer of photoresist 120 is formed 15(o). The photoresist is exposed 122 and developed 15(p). The uncoated portions of silicon nitride are etched and the remaining photoresist removed 15(q).

A metallic plating 124 is sputter coated onto the substrate Figure 15(r) such that connections are formed between some of the lower tracks 116. A further coating of photoresist 126 is deposited Figure 15(s) and exposed and developed. The now exposed portion of the plating layer is etched to reveal the silicon Figure 15(t).

The remaining photoresist is removed and the silicon etched either through wet etching, reactive ion etching or deep reactive ion etching to form a trench 128 Figure 15(u)

The metallic plating mask is then removed and a further seed plate 130, extending over the inner surface of the etched trench, is applied Figures 15(v) and 15(w). The seed plate can form both the active electrode and a keying point for the piezoelectric material 132 which is deposited in the opening to form an actuator having a concave cross-section, Figure 15(x). The piezoelectric material is heated to form a rigid structure and an inner electrode 134 is subsequently formed, Figure 15(y).

The inner electrode and top surface of the actuator component is coated with a protective layer of silicon nitride 136 as depicted in Figure 15(z). To the opposite, lower side of the actuator component a layer of photoresist 138 is applied that is subsequently exposed 140 and developed. The mask is used to

etch the layer of silicon dioxide 104, Figures 15(aa), 15(ab) and 15(ac).

The new coating of photoresist 142 is then applied, exposed 144 and developed and reveals a portion of the sputtered plate 102 that is subsequently removed by etching, Figs 15(ad), 15(ae) and 15(af).

Next, the Silicon base substrate is etched from the lower side to free the piezoelectric actuator structure. The layer of silicon dioxide is removed and a flexible diaphragm plate attached 146, Figure 15(ag), 15(ah), 15(ai).

The embodiment of Figure 16, a to c depict a further method of manufacturing the component using the flexible piezoelectric sheets 26. The flexible sheet is loosely placed adjacent the bottom surface of the body 2 and a cover plate 28 with a port 30 located on the opposite side of the body. The port is used to subject the aperture 4 in the body to reduced pressure that causes the flexible piezoelectric sheet to deform into the aperture as in Figure 16c.

The body and sheet undergoes a step that fixes the flexible sheet within the aperture. The portion of the sheet remaining outside the aperture is removed e.g. by lapping and before depositing the electrode material.

A further embodiment is depicted with regard to Figures 17a to 17c. The silicon body is formed with projections 32. A piezoelectric material is moulded around the projections and then sintered to form the piezoelectric structure 24. Apertures 34 are opened in the body behind the fired piezoelectric structure to free it and the projection is similarly removed.

It is of course possible to provide a mould feature of a material other than silicon by depositing or forming a structure on the silicon base. This material may, for example be a photoresist. By using such materials and open ended channels it is possible to free the actuator without moving any of the silicon material.

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One of the benefits of the reactive ion etching technique used to remove the silicon is that it is a selective process that does not remove the piezoelectric structure.

A cover plate 14 is subsequently attached with a nozzle 16 through which ink is ejected from the ejection chamber 12.

In all the above embodiments the ejection channel is defined by a cover plate 14, the body 2 and the piezoelectric structure. In an alternative embodiment, depicted in Figures 18a and 18b the ejection channel is defined by a planar cover plate and the piezoelectric structure.

The piezoelectric structure 6 is formed as in Figures 13 to 16 above, however it is the inner surface of the piezoelectric structure that defines the ejection channel rather than the outer surface.

The ejection chamber is elongate with two ports 11, 13 positioned at either end. In operation a flow of ink is generated that passes into the channel through one port and from the channel via the other. The flow of ink is preferably sufficient to remove dirt and air bubbles trapped in the channel.

In operation a voltage is applied to the piezoelectric structure to cause it to expand. This initiates an acoustic pressure wave travelling longitudinally up and down the channel. At a position corresponding to the location of the ink supply ports 11, 13 the pressure wave is reflected by the acoustic boundary and travel back up the channel to converge at the nozzle and eject a droplet.

The structure can also be modified as depicted in Figures 19a and 19b. In this

have been drawn as separate components it is equally applicable to provide it them as a single component.

As the piezoelectric structure deforms in use the flexible diaphragm also deforms. Ink is allowed to circulate through the channel as described with reference to Figure 7. The inlet and outlet ports being provided in a separate plate 15.

It is of course possible to form the actuator structure onto a base without it being located in an opening as shown in figure 20.

With piezoelectric actuators a number of different forms of actuation are possible including direct mode, shear mode or bending mode. Direct mode utilises the d33 and d31 modes of piezoelectric material and shear mode d15.

In bending mode a difference in the thickness of the electrodes on either side of the actuator wall causes, when the wall height is reduced during actuation, the walls to bend towards the thicker electrode.

Each feature disclosed in the description, and/or the claims and drawings may be provided independently or in any appropriate combination. In particular any feature of a subsidiary claim may be incorporated in a claim for which it is not dependent.

Also, any described channelled component and any described actuator component may be utilised together.

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Claims

1. An actuator component for a drop on demand ink jet printer, said component comprising a body having a top surface, an opening in said top surface extending into said body, an actuator structure located substantially within in said opening and electrode means; said electrode means being disposed so as to be able to apply a field to said actuator structure so as to cause said actuator structure to deform.

2. A component according to Claim 1, wherein said actuator structure is an isolated actuator structures.

3. A component according to Claim 1 or Claim 2, wherein said openings extend into said body. in a direction substantially perpendicular to said top surface; said direction lying on an opening axis.

4. A component according to any preceding claim, wherein said actuator structure tapers along said opening axis.

5. A component according to any preceding claim, wherein said actuator structure is convex.

6. A component according to any preceding claim, wherein a plurality of openings is provided; each of said openings comprising a respective actuator structure.

7. A component according to any preceding claim, wherein said openings are bounded by at least one opening surface; said opening surface lying perpendicular to said top surface.

8. A component according to Claim 7, wherein said opening surface

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extends radially around said opening.

9. A component according to Claim 7, wherein a plurality of opening surfaces are provided.

10. A component according to Claim 9, wherein said plurality of opening surfaces define an opening that is elongate in a direction perpendicular to said opening axis; said opening being a channel.

11. A component according to any one of Claim 7 to Claim 10, wherein said actuator structure is attached to an opening surface at a point of attachment.

12. A component according to Claim 11, wherein said point of attachment extends substantially around said opening.

13. A component according to any preceding claim, wherein said actuator is formed of electrostrictive material.

14. A component for ejecting a droplet in a direction of droplet flight, said component comprising an actuator structure displaceable by actuation in the direction of said droplet flight; said actuator defining in part an ejection chamber and comprising a port through which said droplet is ejected.

14. A component according to Claim 14, comprising electrode means, said electrode means being disposed so as to be able to apply a field to said actuator structure so as to cause said actuator structure to deform.

15. A component according to Claim 14 or Claim 15, wherein said actuator structure comprises elongate channel walls defining an elongate channel.

16. A component according to Claim 15, wherein said actuator structure

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provides a convex cross section when a cross section is taken orthogonal to the channel length.

17. A component according to Claim 16, wherein said actuator structure is homogenous.

18. A component according to Claim 16 or Claim 17, wherein said port is provided in the roof of said convex cross-section.

19. A component according to any one of Claim 14 to Claim 18, wherein said actuator structure is mounted to a base; said base providing one wall of said ejection chamber.

20. A component for a drop on demand ink jet printer, said component comprising a body having a plurality of openings extending into said body, actuator structures located substantially within each opening wherein said actuator structure is formed by a process of electrophoresis.

21. A component for a drop on demand ink jet printer, said component comprising a body having a plurality of openings extending into said body, actuator structures located substantially within each opening wherein said actuator structure is formed by a process of sputtering.

22. A component for a drop on demand ink jet printer, said component comprising a body having a plurality of openings extending into said body, actuator structures located substantially within each opening wherein said actuator structure is formed by a process of vacuum forming.

23. A method of forming a component for an ink jet print head comprising the steps a) providing a body having a mould feature, b) forming a deformable actuator structure, the shape of said actuator structure being defined, at least in

part by said mould feature, c) removing at least a portion of said mould feature and d) providing electrode means; said electrode means being disposed so as to be able to apply a field to said actuator structure so as to cause said actuator structure to deform whilst said actuator structure is attached to said body.

24. A method according to Claim 23, wherein said mould feature is provided by adding a material to a surface of said body.

25. A method according to Claim 24, wherein said surface is a top surface.

26. A method according to Claim 24, wherein said surface is a surface bounding an opening extending into said body.

27. A method according to any one of Claim 23 to Claim 26, wherein said material is added by a method comprising the steps a) depositing a photo resist, b) masking said photo resist, c) developing said photoresist thereby hardening portions of said photoresist and d) washing unhardened portions.

28. A method according to Claim 23, wherein said mould feature is provided by removing material from a surface of said body.

29. A method according to Claim 28, wherein said material is removed by etching.

30. A method according to Claim 23, wherein the step of forming said electrode means comprises a first step of forming a first electrode layer and a second step of forming a second electrode layer.

31. A method according to Claim 30, wherein said first electrode layer is formed before forming said deformable actuator structure.

32. A method according to Claim 30, wherein said first electrode means are immersed in a suspension comprising dispersed particles.

33. A method according to Claim 32, wherein said dispersed particles comprise piezoelectric material.

34. A method according to Claim 32 or 33 wherein a deposition electrode is immersed in said suspension with said first electrode means for applying a voltage therebetween and thereby depositing said dispersed particles on said first electrode means.

35. A method according to any one of Claim 30 to Claim 34, wherein said second electrode layer is formed after forming said deformable actuator structure.

36. A method according to Claim 23, wherein the step of removing at least a portion of said mould feature is achieved by etching.

37. A method according to Claim 23, wherein the step of removing at least a portion of said mould feature is achieved by washing.

38. A method according to Claim 23, wherein the step of removing at least a portion of said mould feature is achieved by firing.

39. A method of forming a component for an ink jet print head comprising the steps a) providing a body having a top surface, b) forming an opening in said top surface and extending into said body and; c) forming within said opening an actuator structure; said actuator structure remaining attached to said body during actuation.

40. A method according to Claim 39, wherein said actuator structures are

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isolated actuator structures.

41. A method according to Claim 39 or Claim 40, comprising the step of forming a plurality of openings.

42. A method according to any one of Claim 39 to Claim 41, wherein the step of forming said opening by etching material from said top surface.

43. A method according to Claim 42, wherein a mask is applied to the body and the opening thus formed tapers with increasing depth.

44. A method according to any one of Claim 39 to Claim 43, wherein electrode means are applied to an inner surface of said opening.

45. A method according to Claim 44 wherein said electrode means are immersed in a suspension comprising dispersed particles.

46. A method according to Claim 45, wherein said dispersed particles comprise piezoelectric material.

47. A method according to Claim 45 or 46 wherein a deposition electrode is immersed in said suspension with said first electrode means for applying a voltage therebetween and thereby depositing said dispersed particles on said first electrode means.

48. A method according to Claim 47, wherein said deposited dispersed particles are heated to form said actuator structure.

49. A method according to any one of Claim 39 to Claim 44, wherein a slurry comprising particles is moulded within said opening, the structure formed at least partly conforming to the shape of said opening.

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50. A method according to Claim 49, wherein said particles are of a piezoelectric material.

51. A method according to Claim 49 or Claim 50, wherein said moulded particles are heat treated to form said actuator structure.

52. A method according to any one of Claim 39 to Claim 44, wherein a flexible sheet of a piezoelectric material is laid within said opening by applying a pressure difference thereto; said sheet at least partly conforming to the shape of said opening.

53. A method according to Claim 52, wherein said sheet is heat treated to form said actuator structure.

54. A method according to any one of Claim 39 to Claim 44, wherein a film of piezoelectric material is deposited within said opening using a sputtering process; said film at least partly conforming to the shape of said opening.

55. A method according to Claim 54, wherein said sputtering process comprises three metal targets of Lead, Titanium and Zirconium.

56. A method according to any one of Claim 54 to Claim 55, wherein said film is heat treated to form said actuator structure.

57. A channelled component for a drop on demand ink jet printer comprising elongate channel walls defining a plurality of elongate liquid channels, each channel comprising one wall that is resiliently deformable in an actuation direction orthogonal to the channel length; a respective ejection nozzle connected with the channel at a point intermediate its length; a liquid supply providing for continuous flow of liquid along said channel; acoustic boundaries at

respective opposite ends of the channel serving to reflect acoustic waves in the liquid of the channel wherein the inter-channel spacing of said acoustic boundaries is different to the inter-channel spacing of said nozzles.

58. A channelled component according to Claim 57, wherein the inter-channel spacing of said acoustic boundaries is less than that of the inter-channel spacing of said nozzles.

59. A channelled component according to Claim 58, wherein channels are chevron shaped.

60. A channelled component according to Claim 59, wherein a series of chevron shaped channels is arranged to one side of a straight channel, the angle of said chevron shaped channels being more acute with increasing distance from said straight channel.

61. A channelled component according to Claim 60, wherein a reversed second series of chevron shaped channels is arranged on the opposite side of said straight channel.

62. A channelled component according to any one of Claim 57 to Claim 61, wherein said channels are arranged on a tile, an array of nozzles extending linearly across said tile.

63. A channelled component according to Claim 62, wherein a plurality of like tiles are butted together along respective edges and wherein there is provided an array nozzles having an equal linear nozzle spacing across the width of the like tiles and across the butt joint.

64. A channelled component according to Claim 63, wherein said respective edges are serrated.

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65. A channelled component according to Claim 64, wherein the serrations of respective edges are interleaved.

66. An inkjet print head comprising an actuator component of any one of Claim 1 to Claim 58 in combination with a channelled component of Claim 57 to Claim 65.

67. Apparatus as substantially hereinbefore described.

68. A method of manufacture as substantially hereinbefore described.

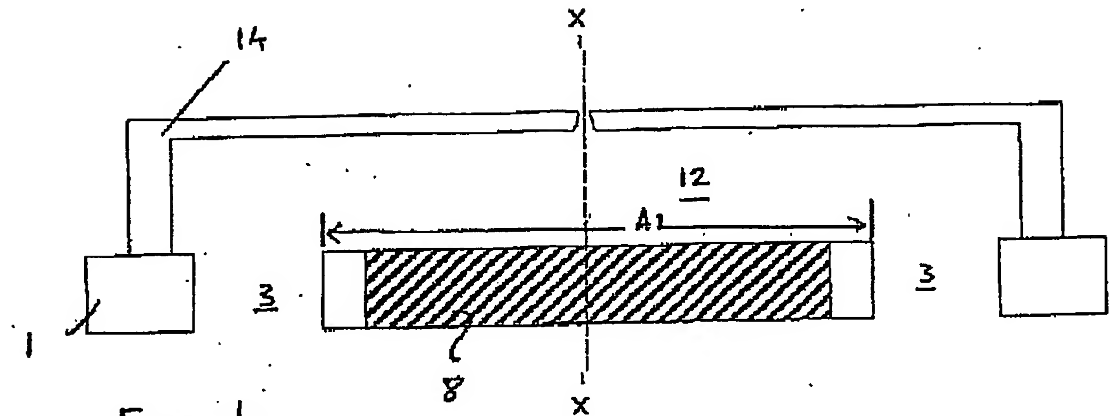

Figure 1a

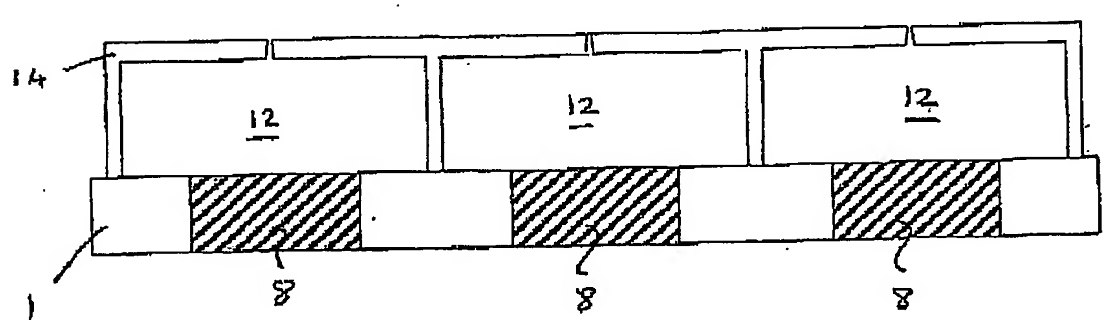

Figure 1b.

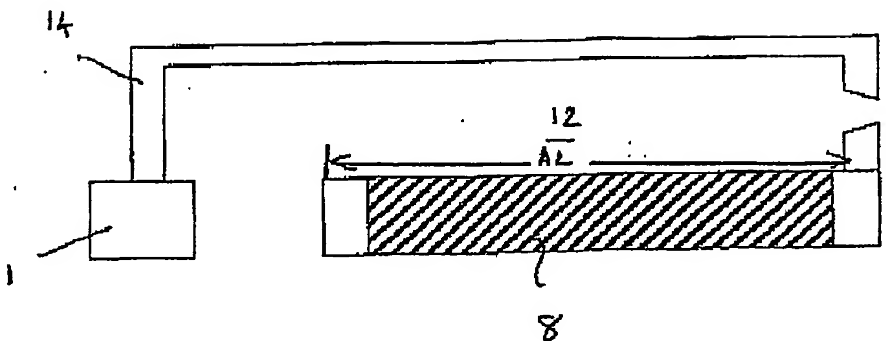

Figure 1c

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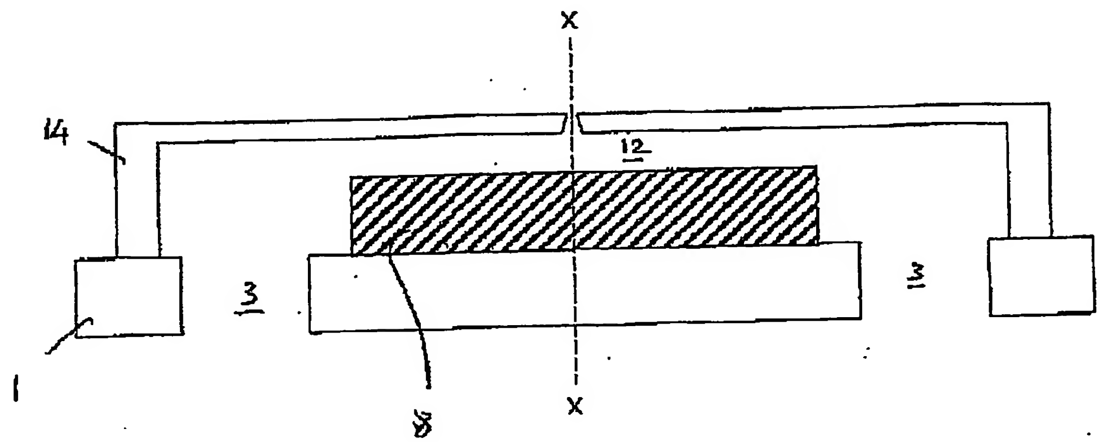

Figure 2a

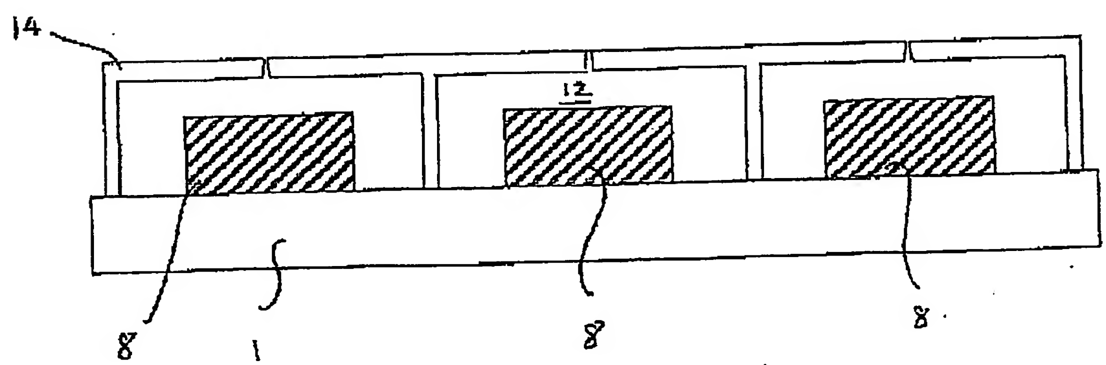

Figure 2b

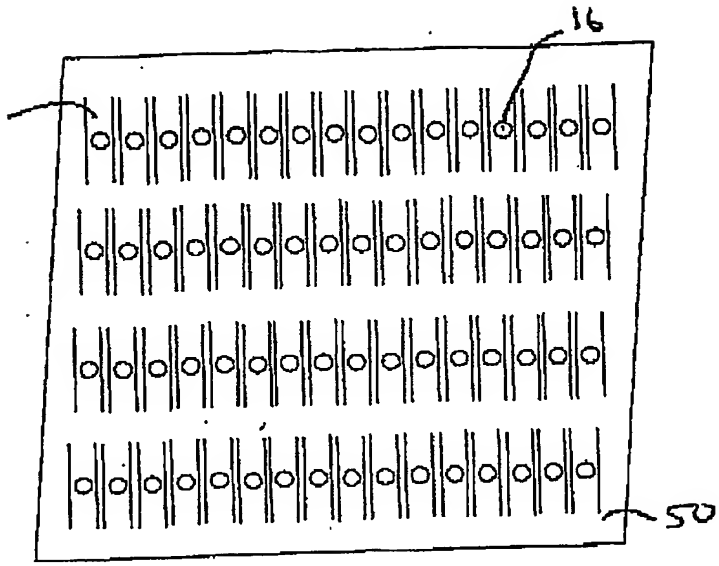

Figure 3

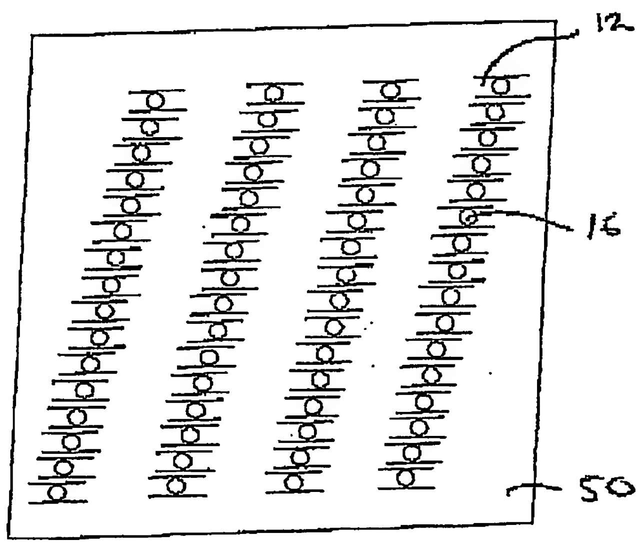

Figure 4

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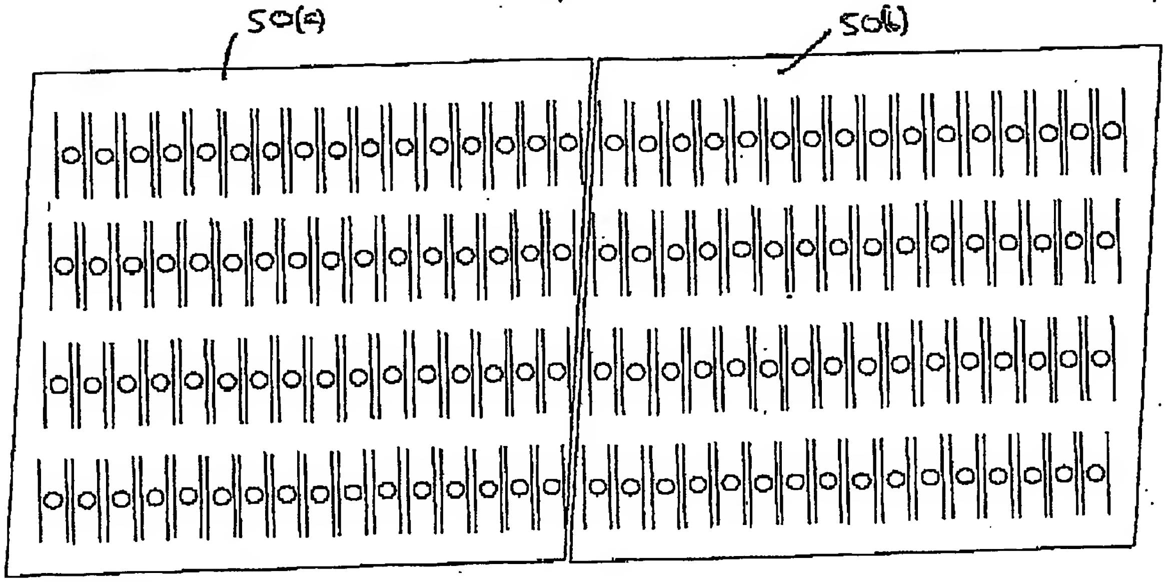

Figure 5

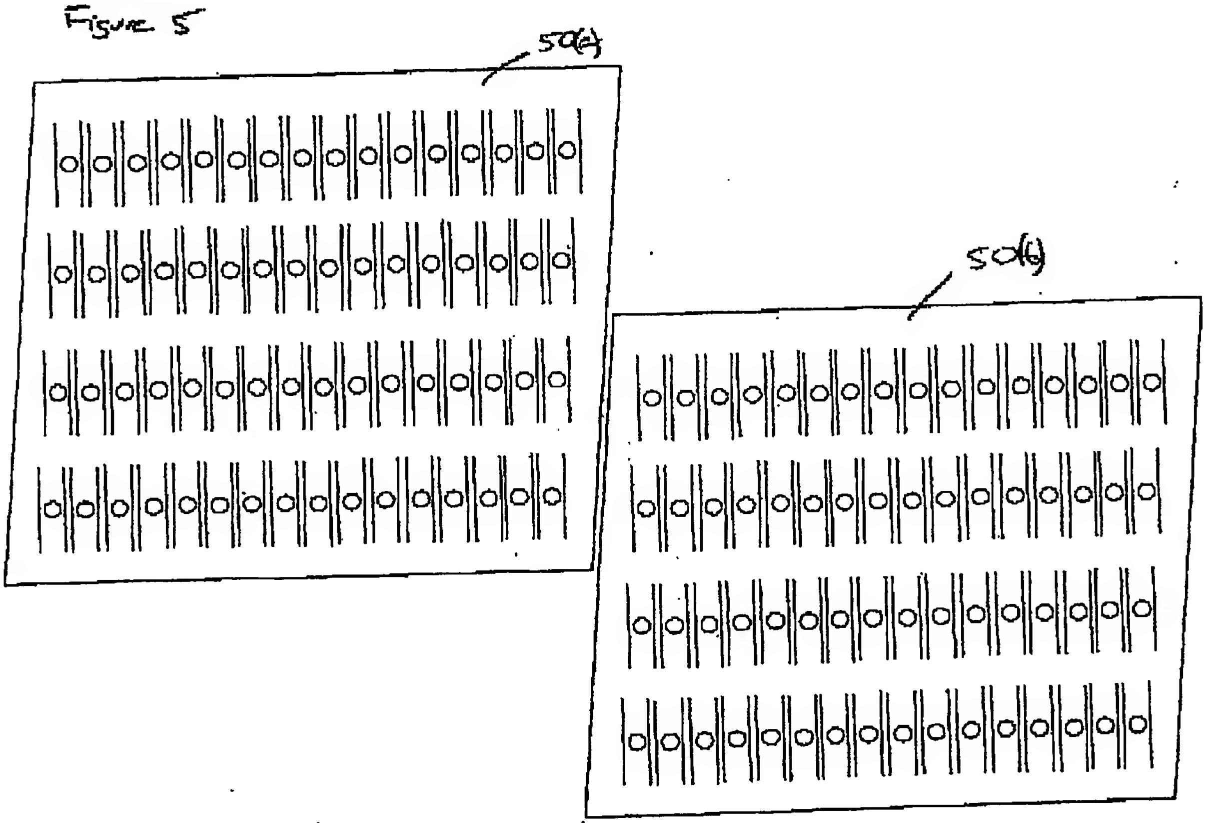

Figure 6

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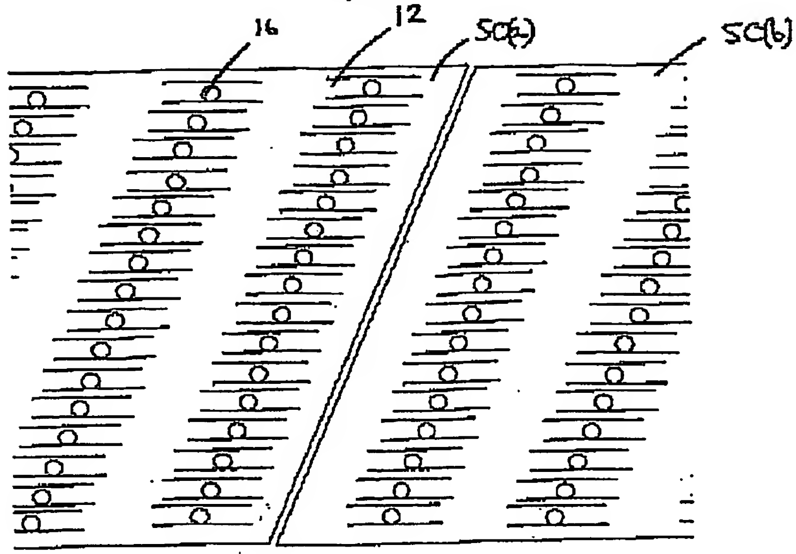

Figure 7

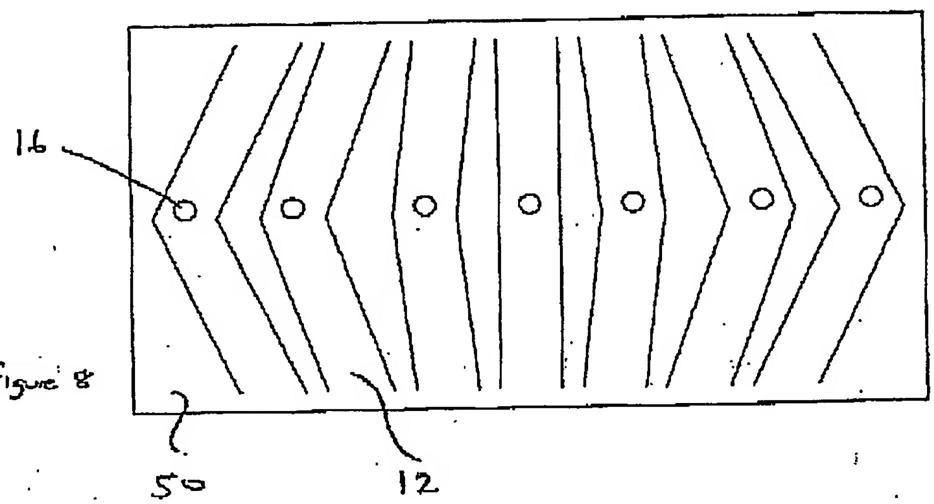

Figure 8

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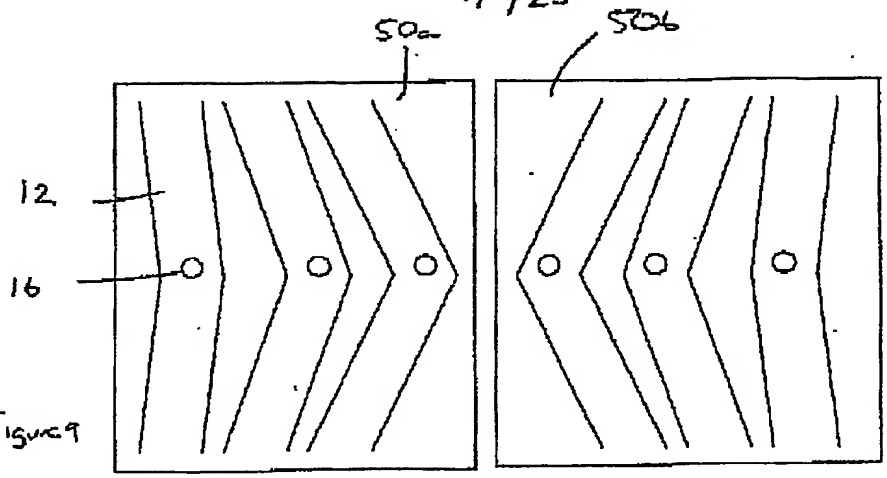


Figure 9

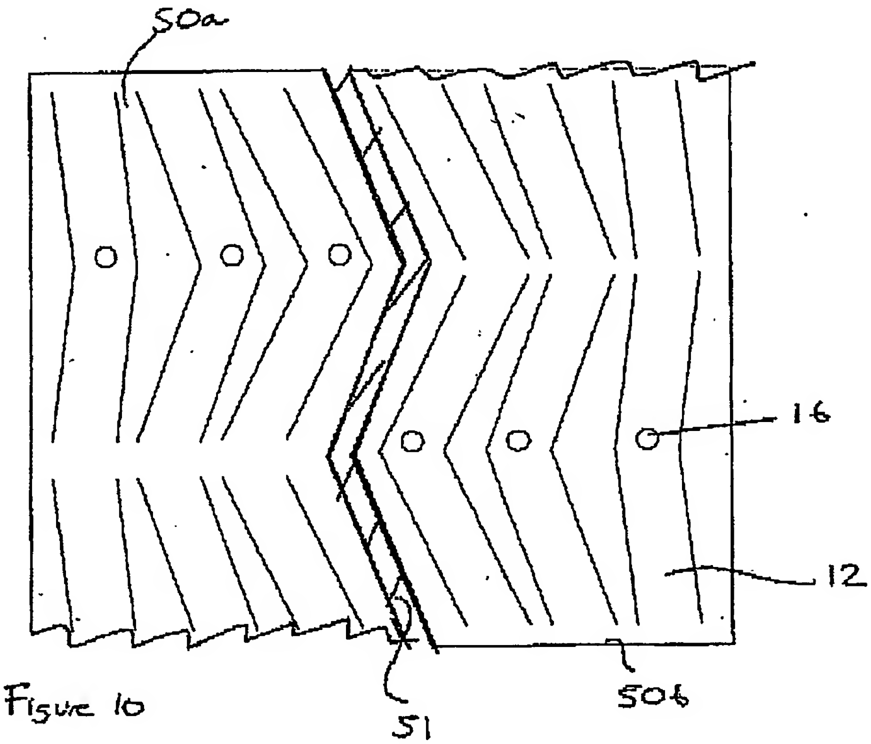


Figure 10

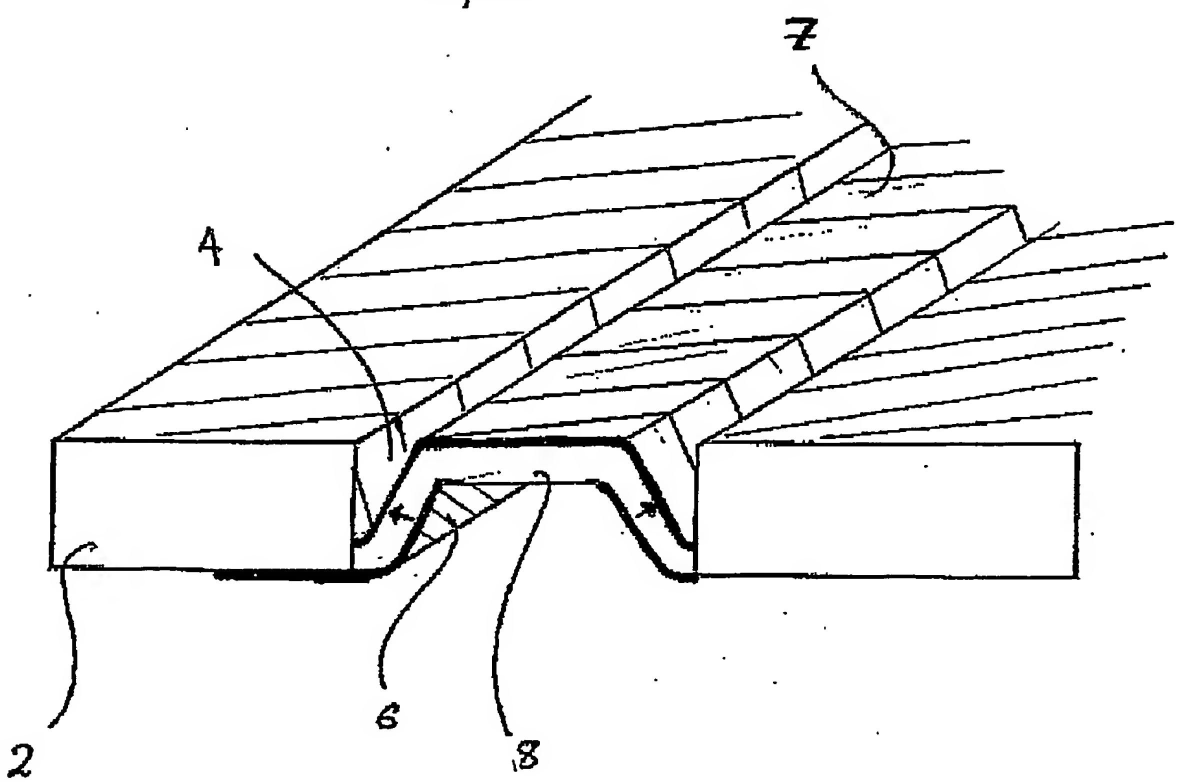


Figure 11

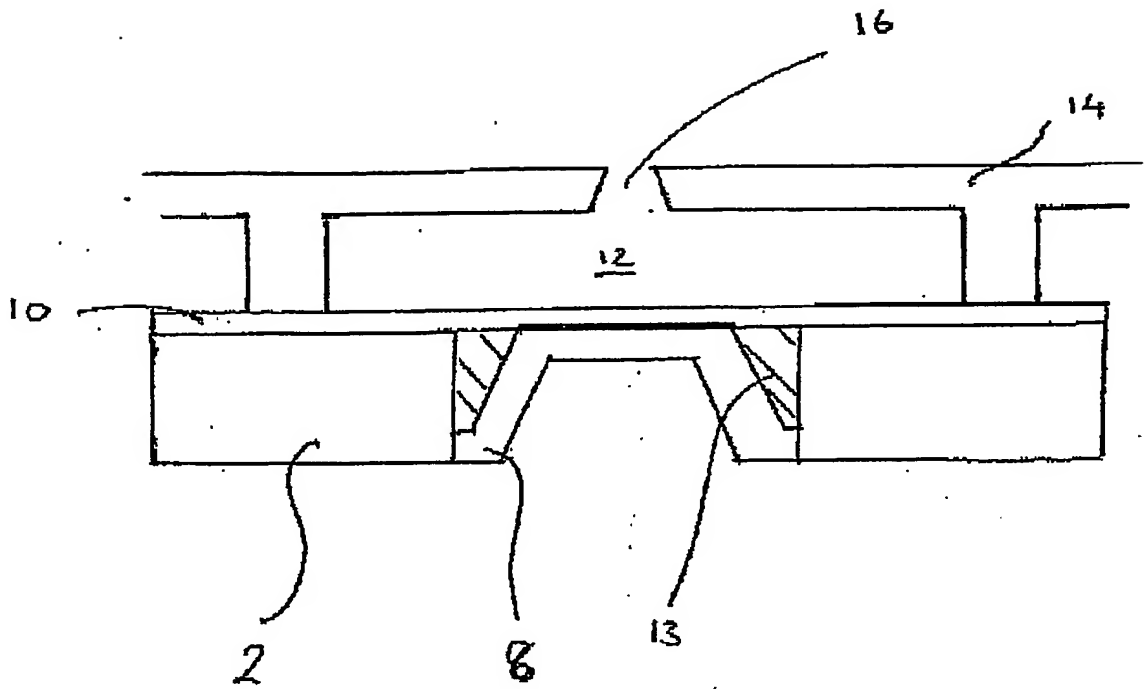


Figure 12

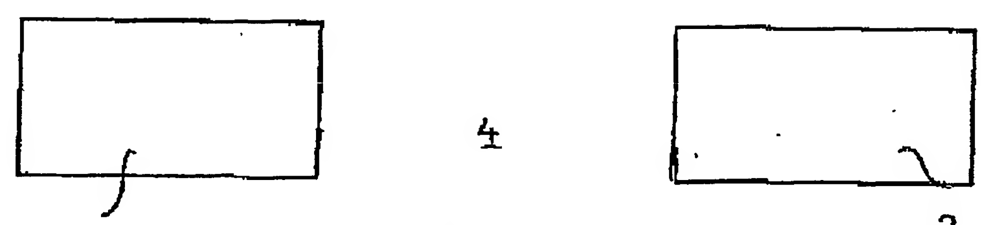


Figure 13a.

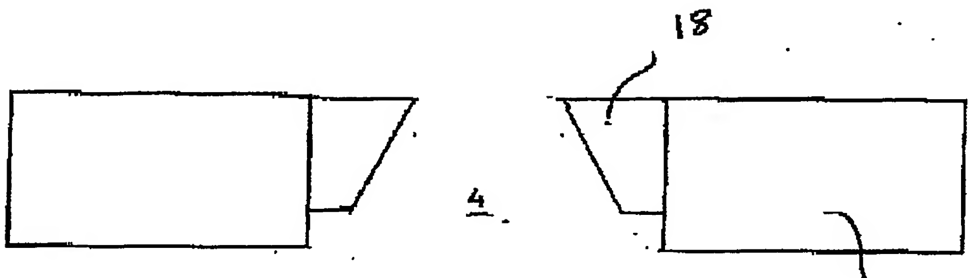


Figure 13b.

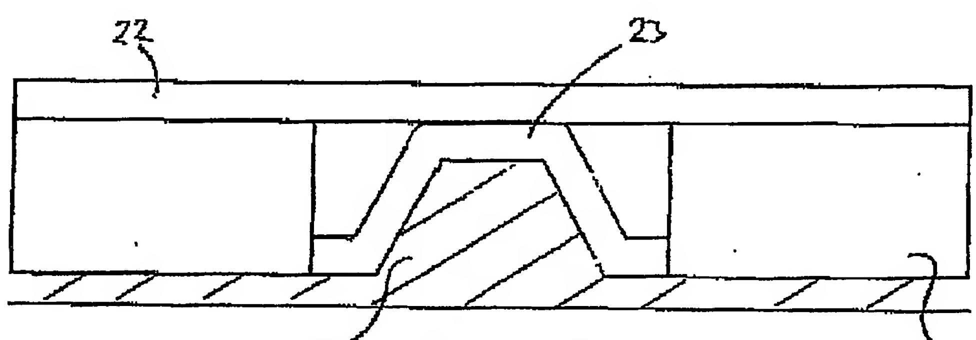


Figure 13c

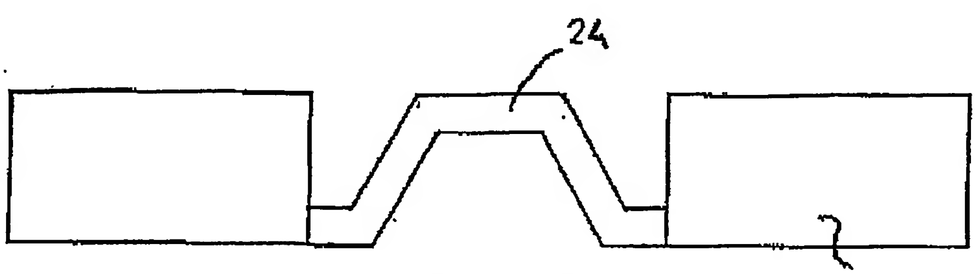


Figure 13d.

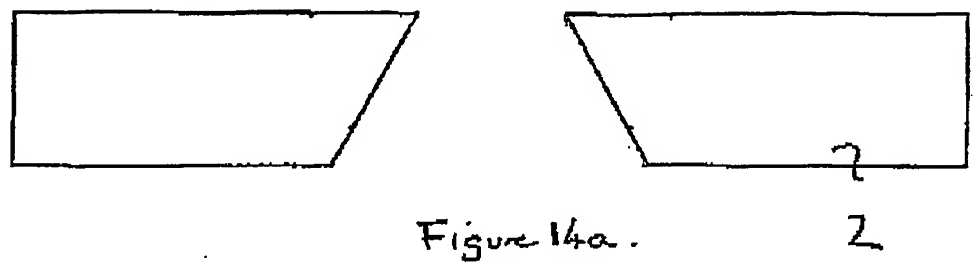
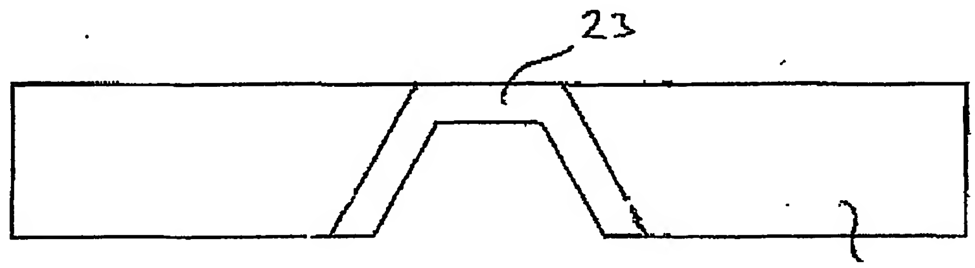


Figure 14a.



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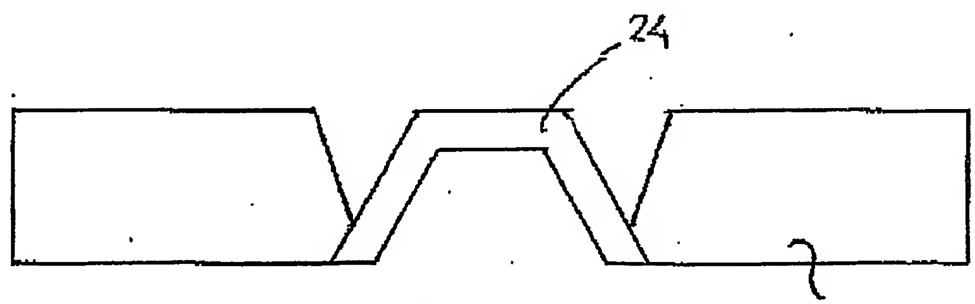

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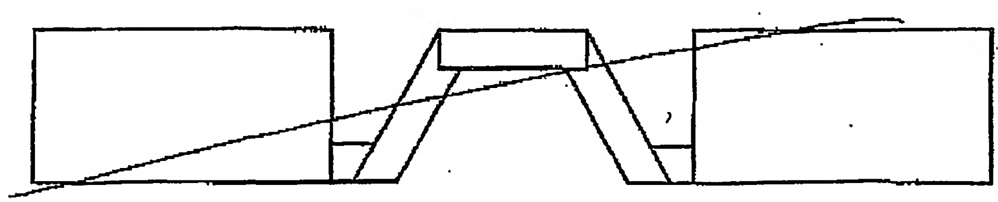

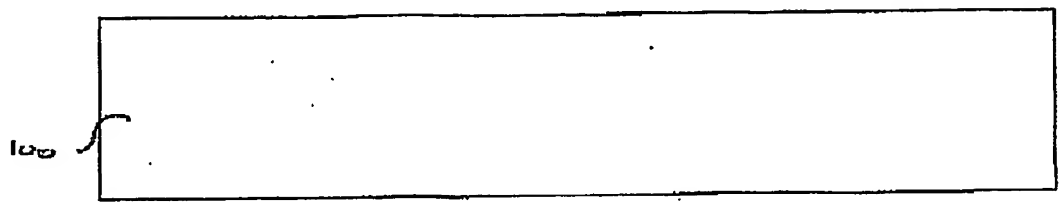

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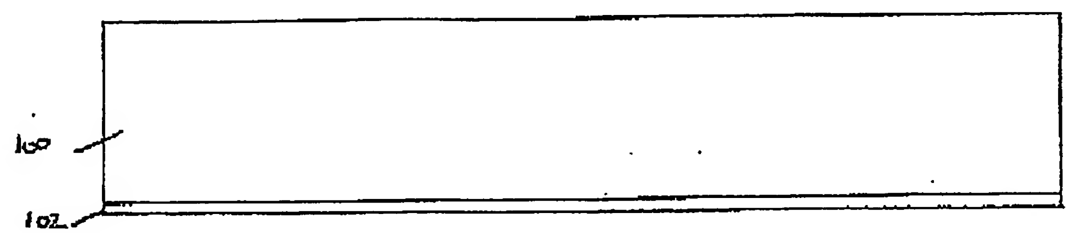

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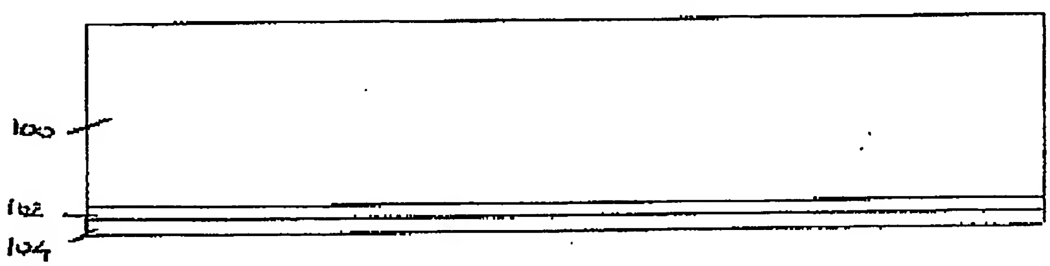

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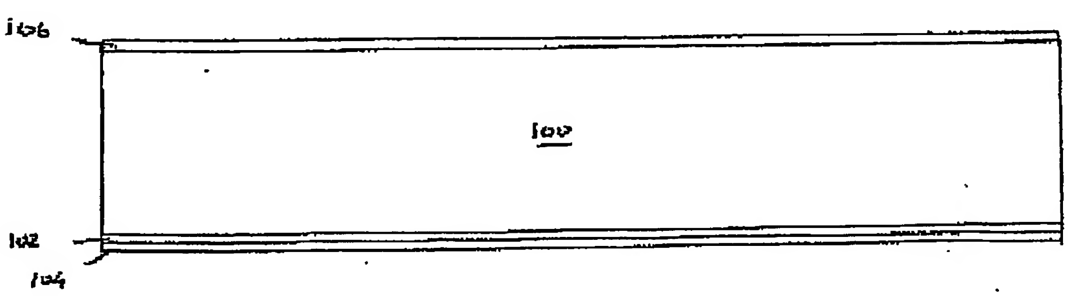

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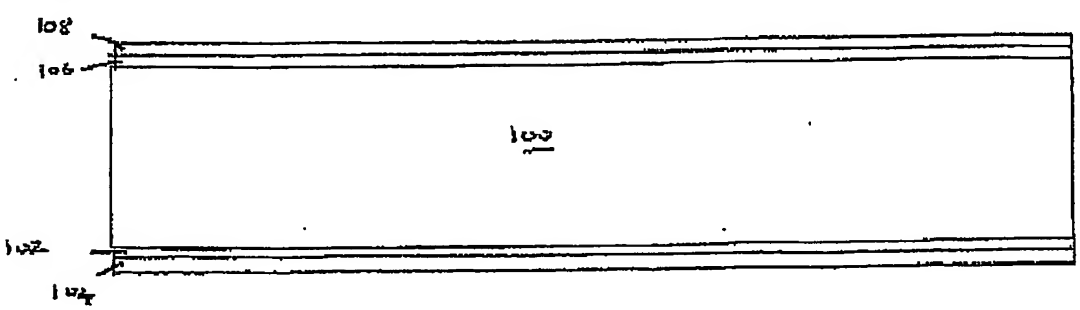

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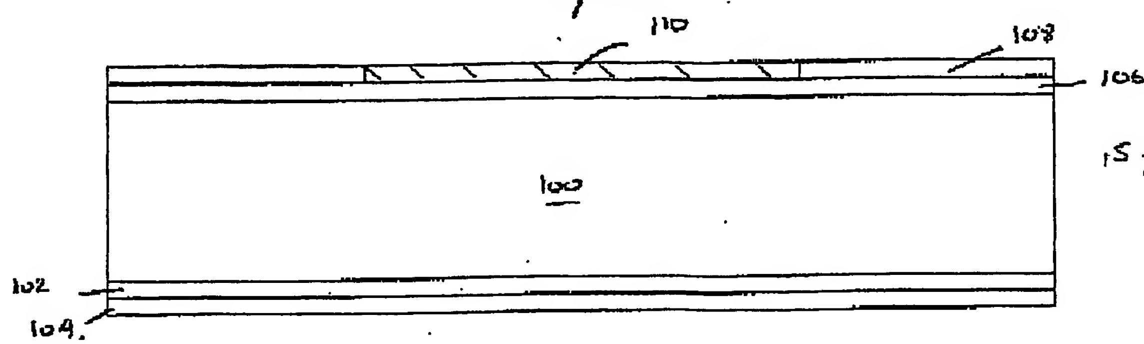

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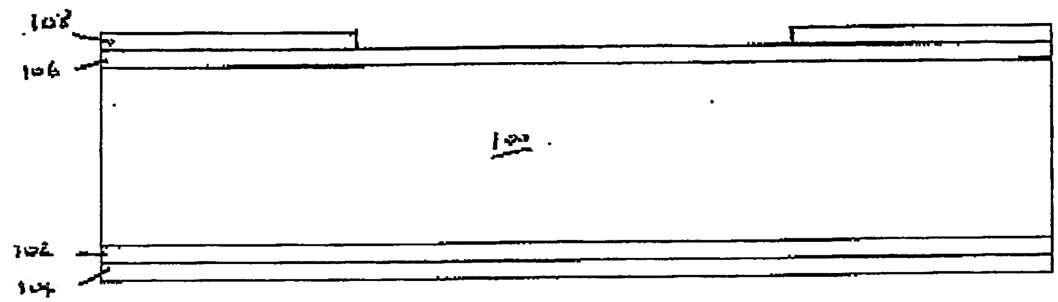

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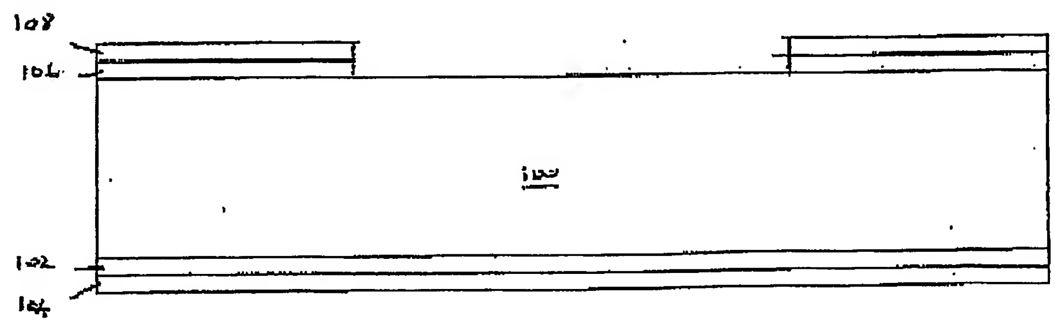

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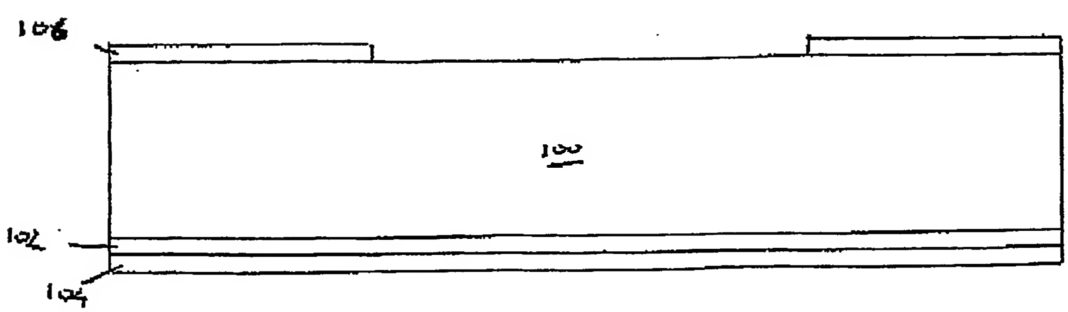

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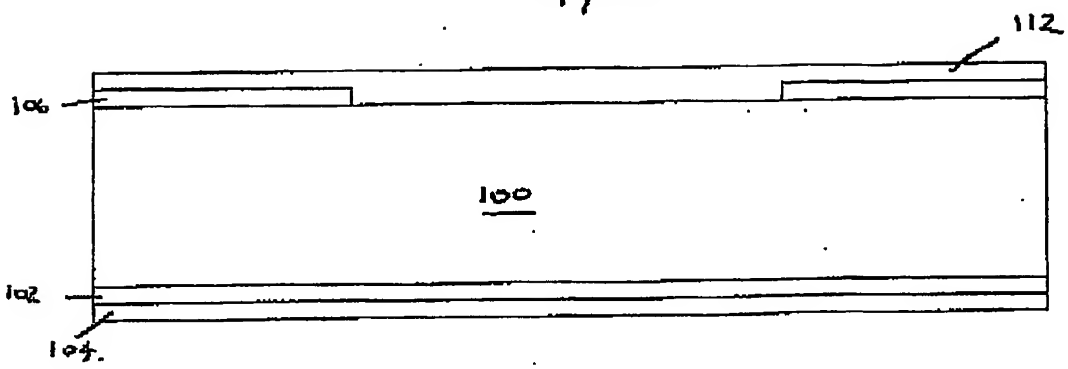

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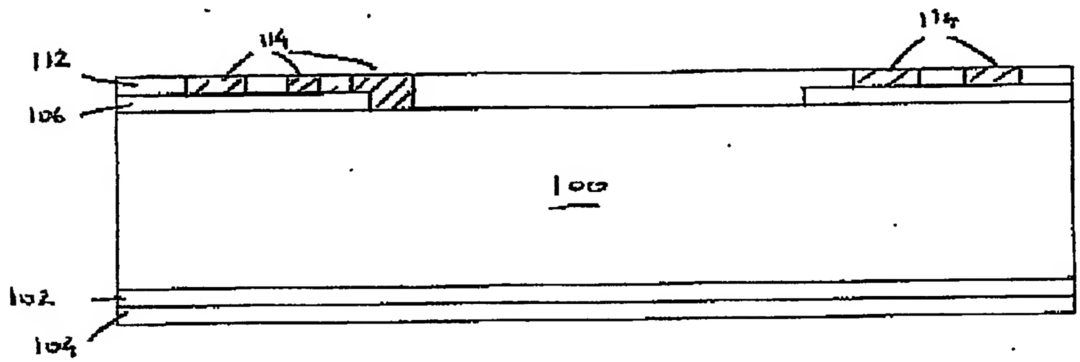

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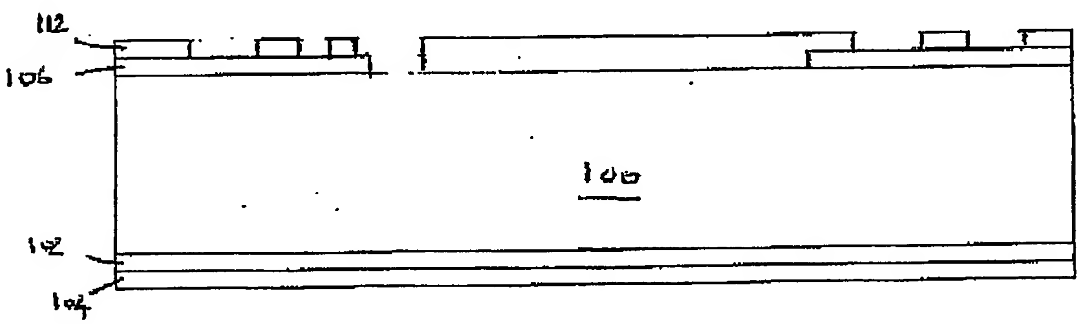

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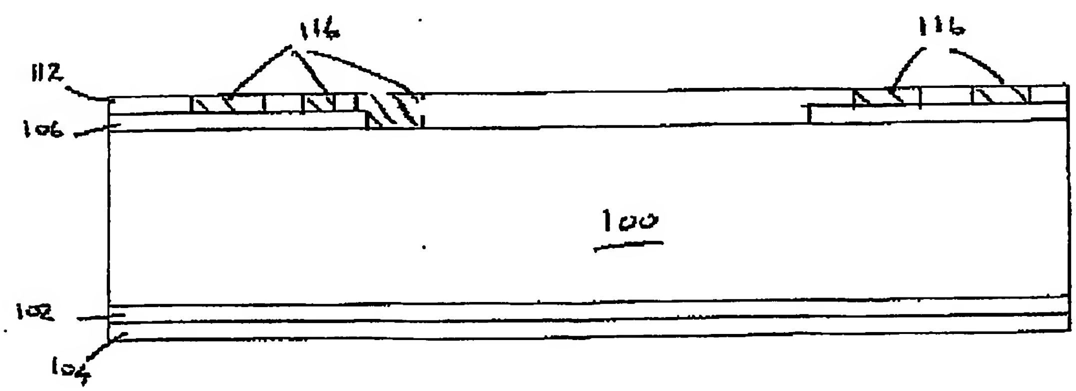

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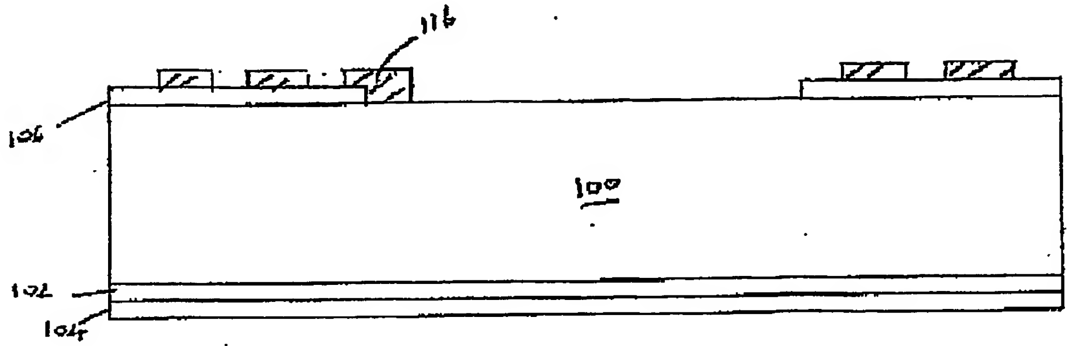

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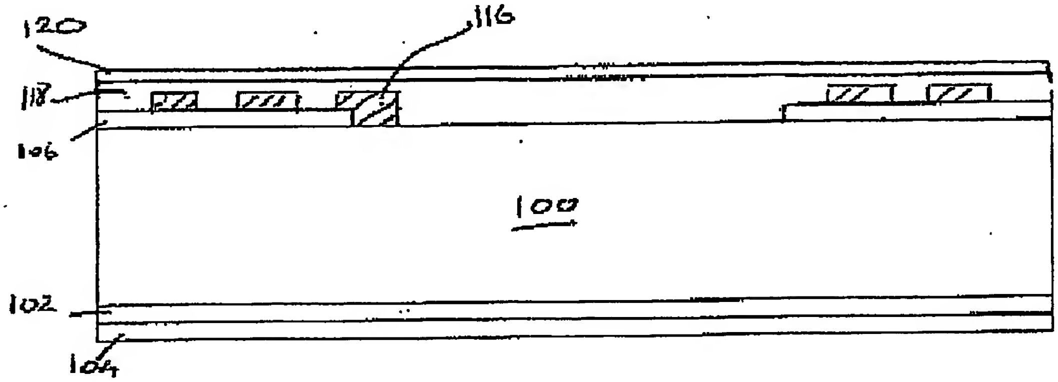

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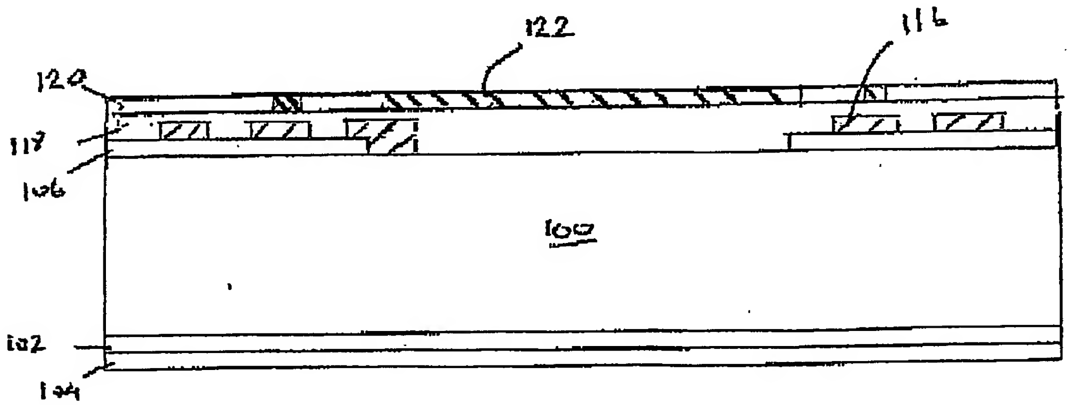

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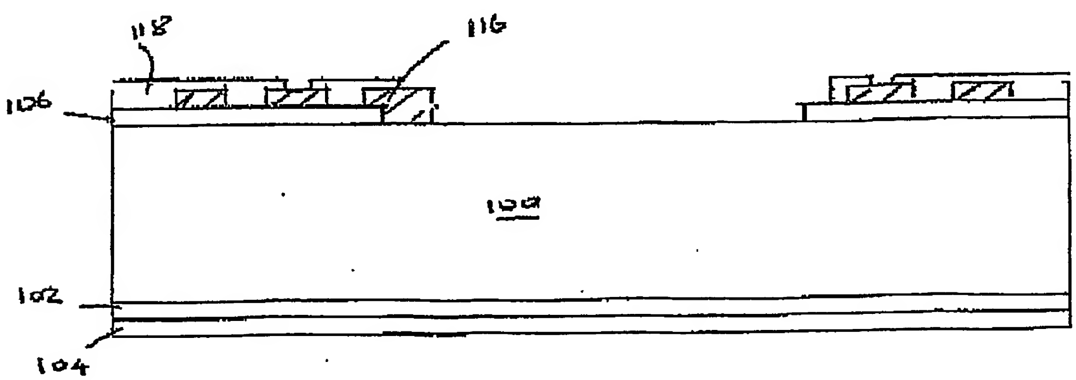

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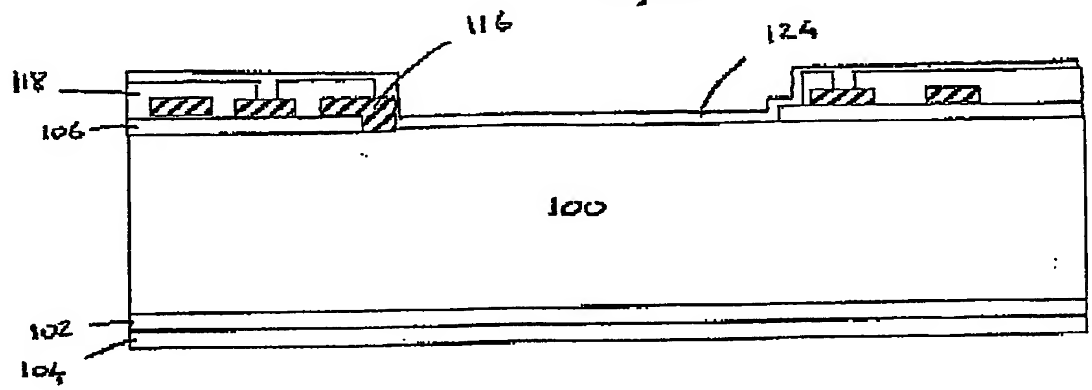

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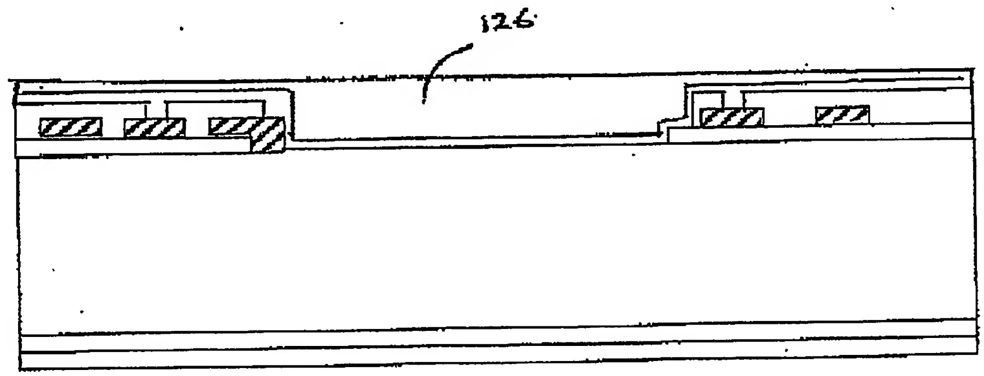

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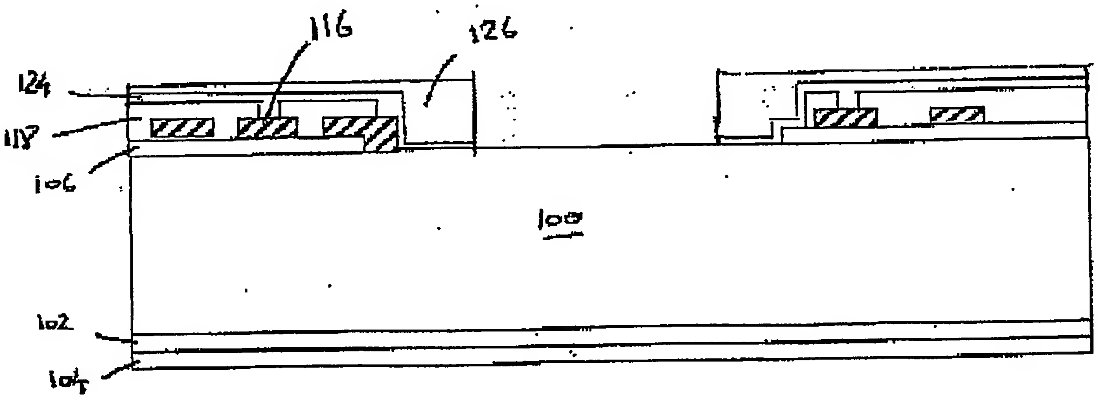

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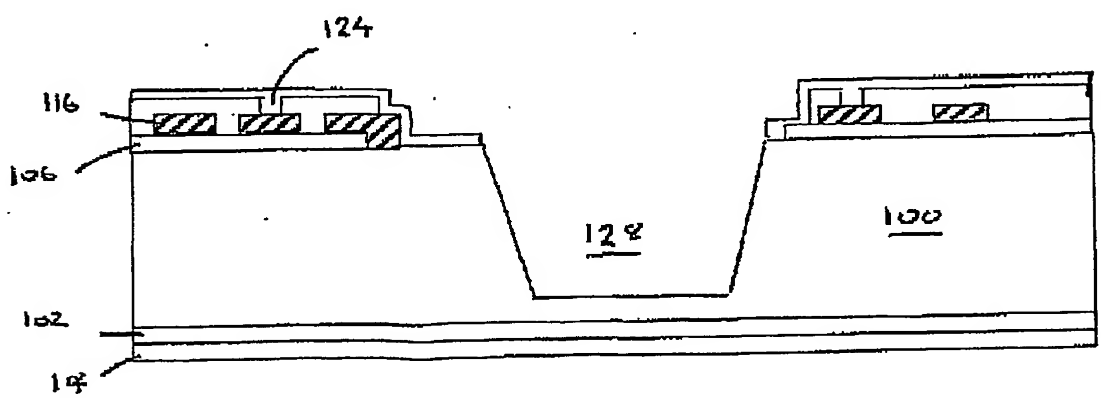

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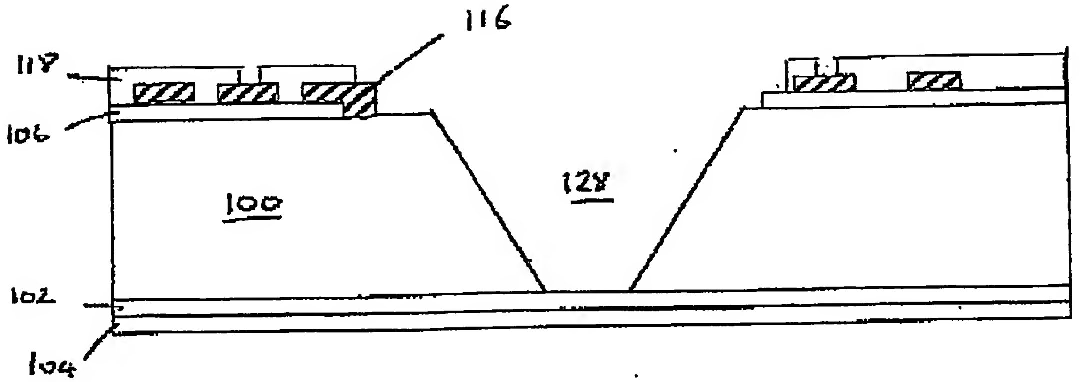

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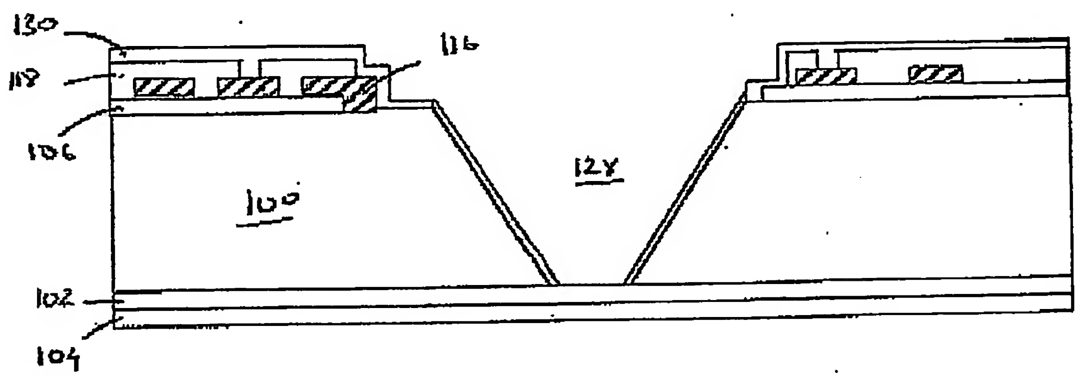

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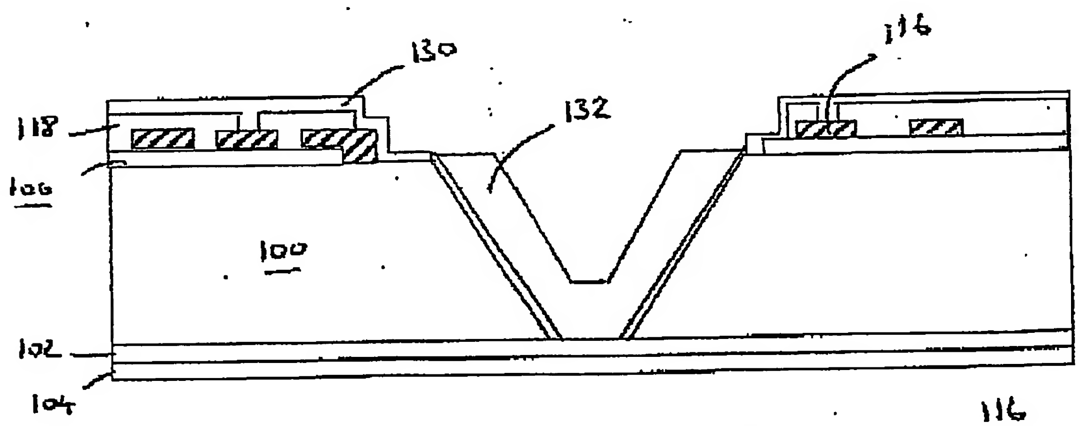

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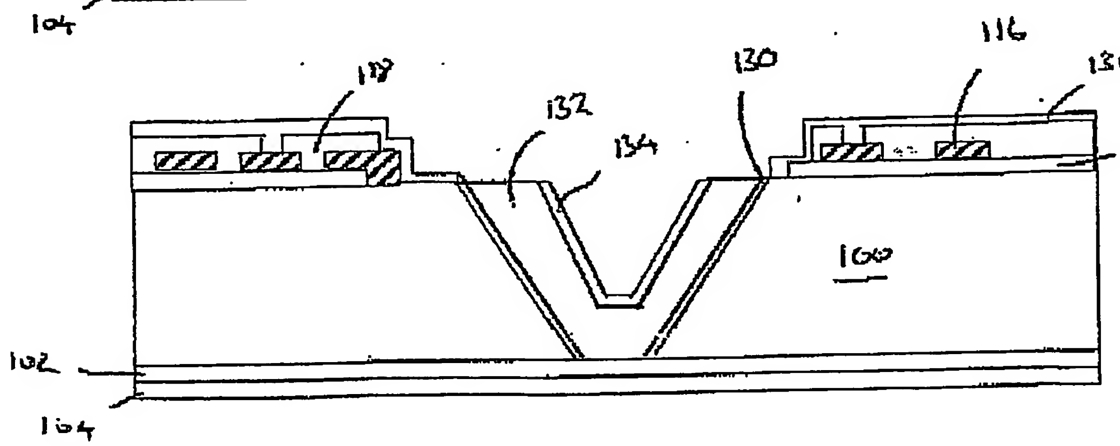

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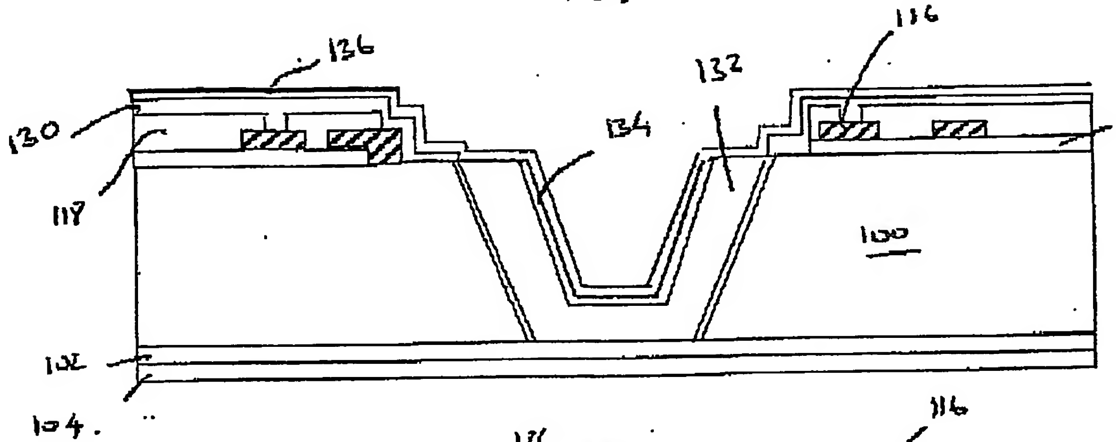

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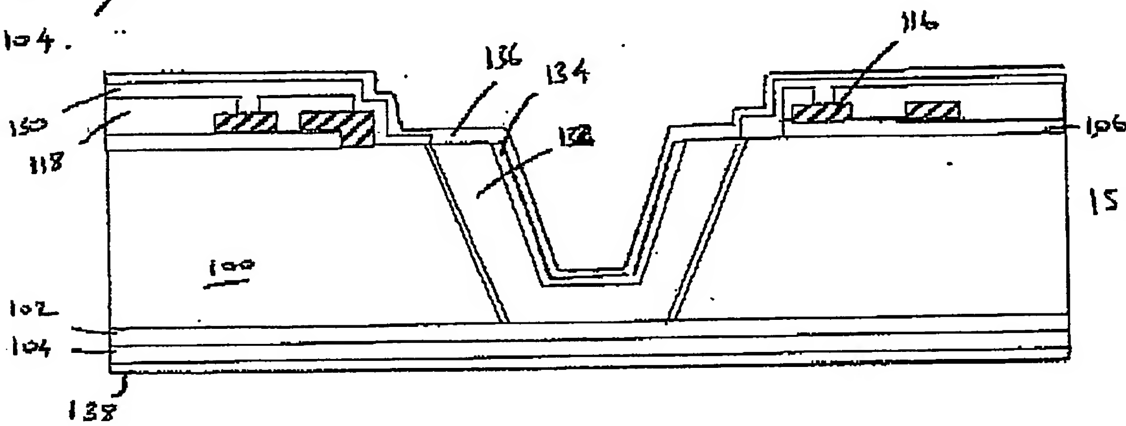

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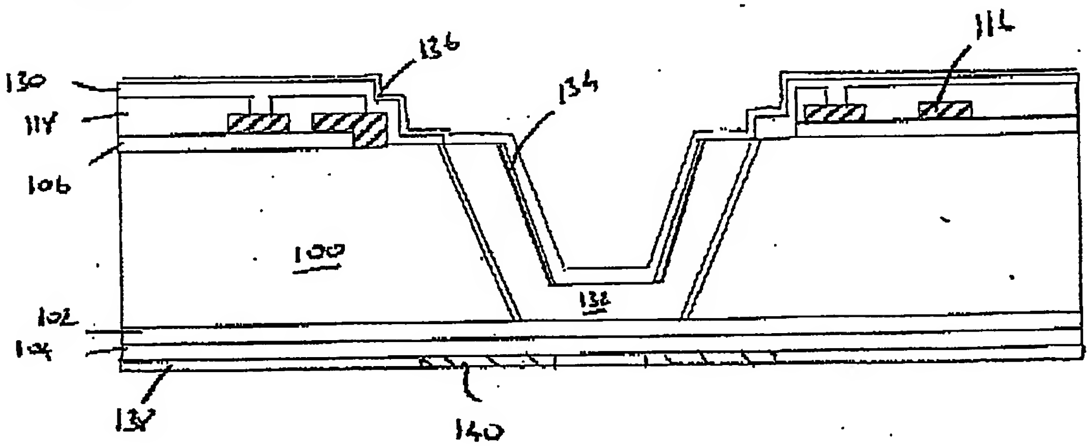

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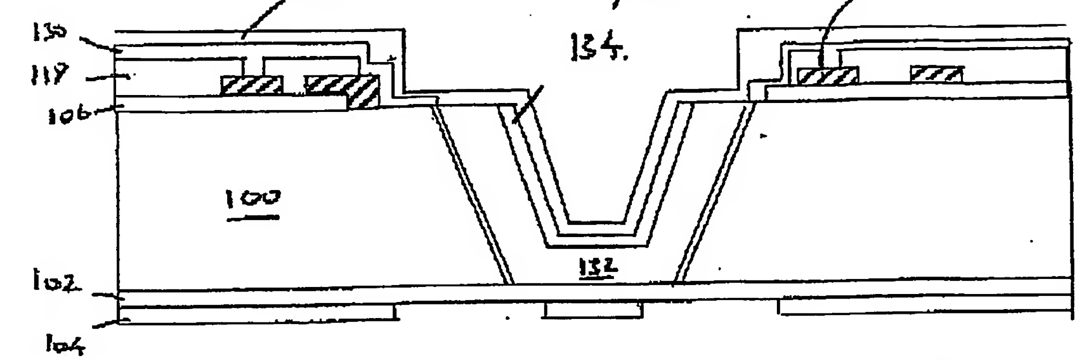

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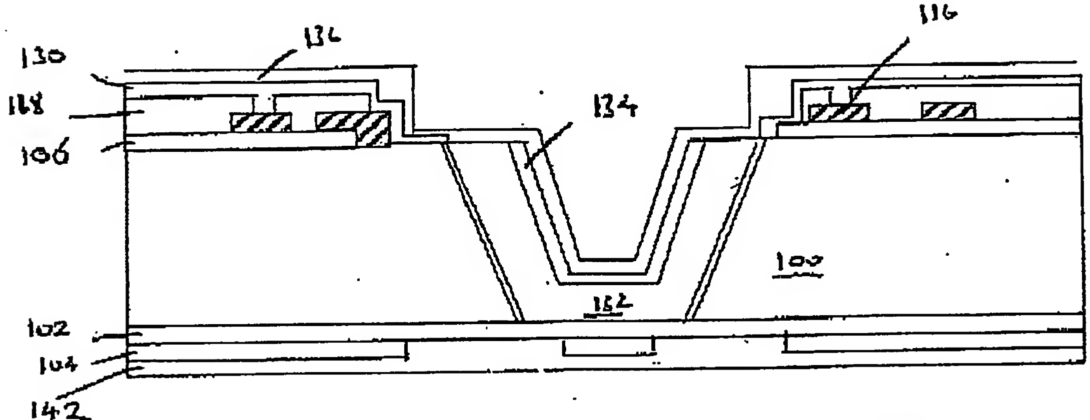

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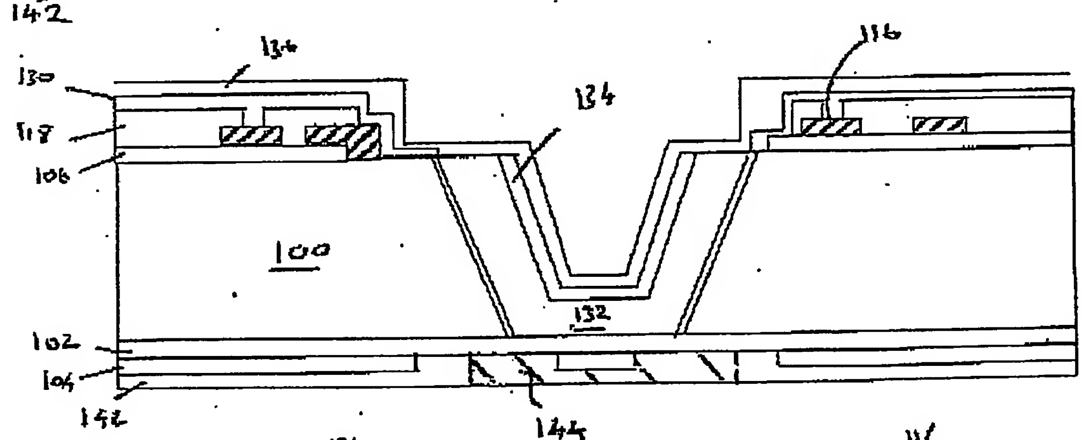

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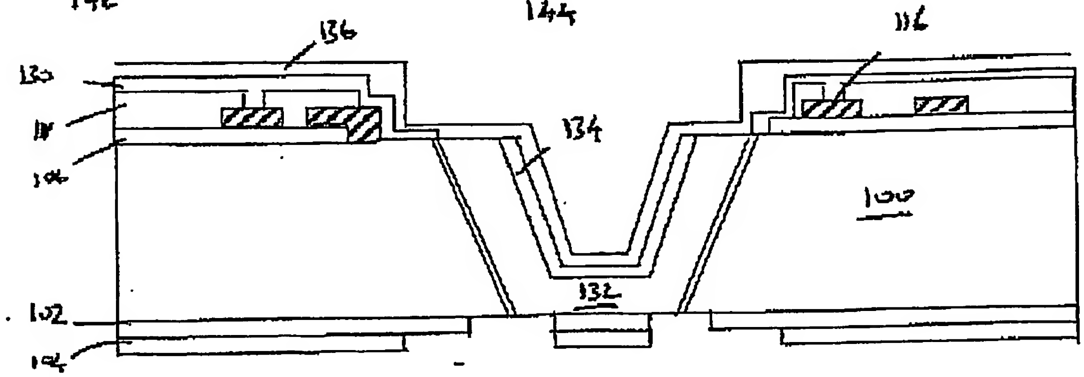

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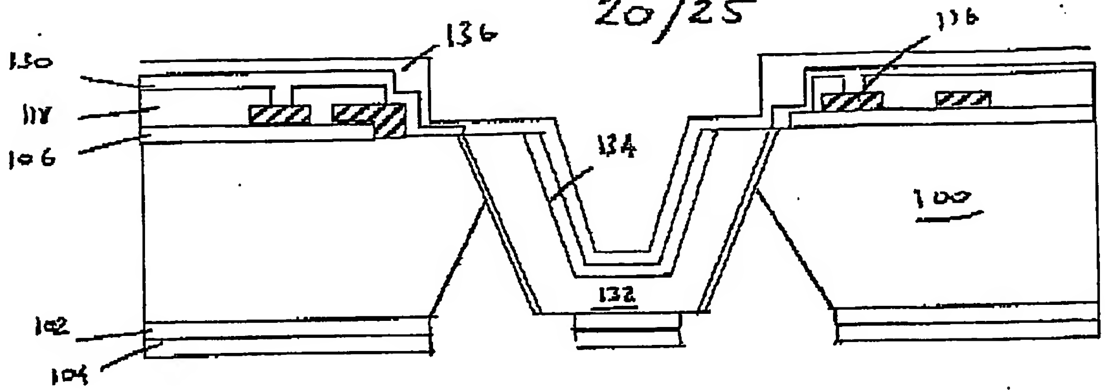

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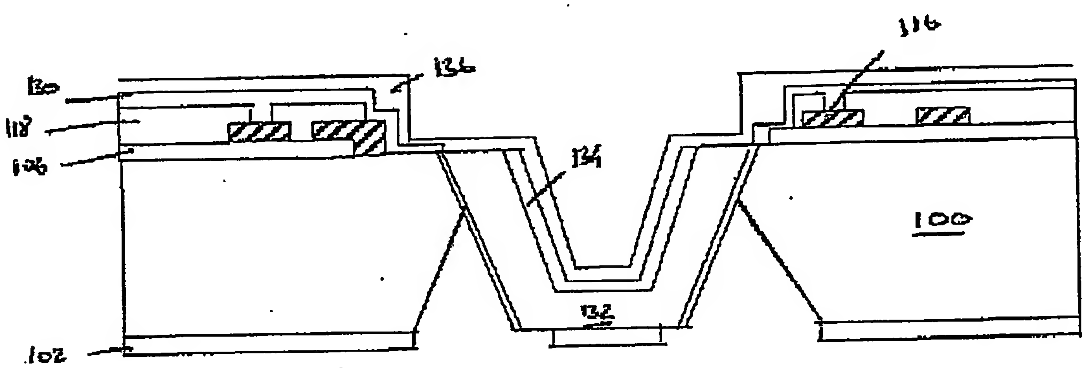

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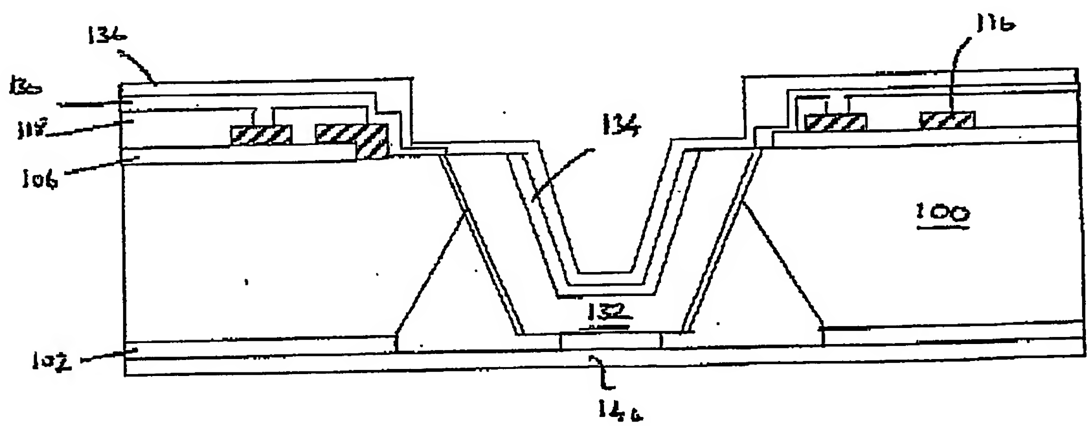

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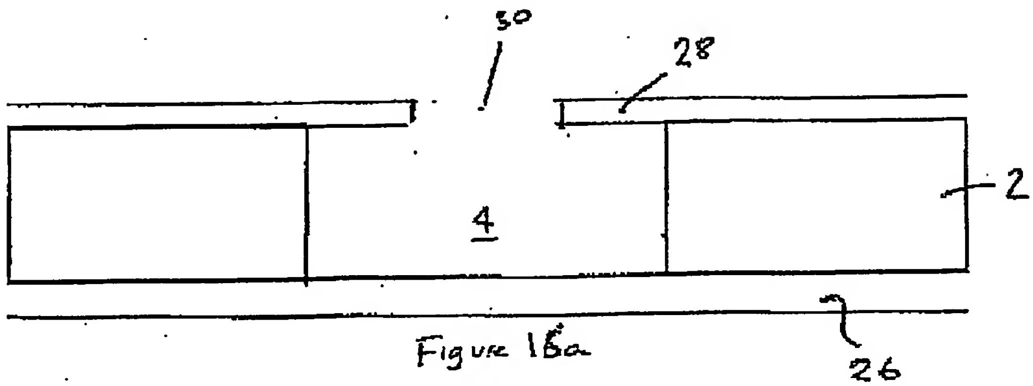

Figure 18a

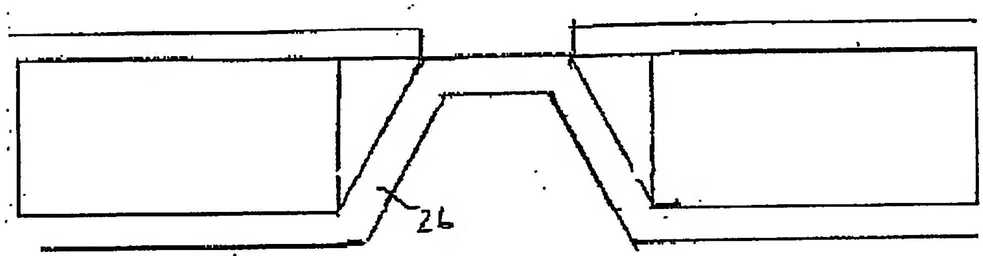

Figure 18b

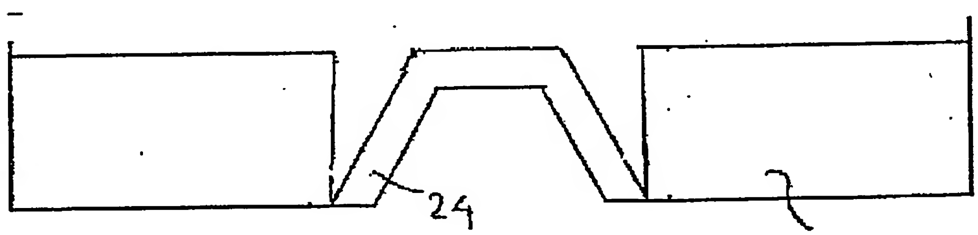

Figure 18c

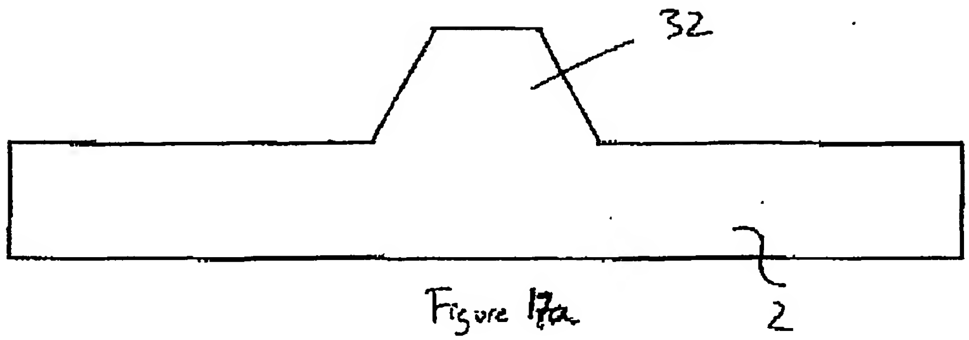

Figure 17a

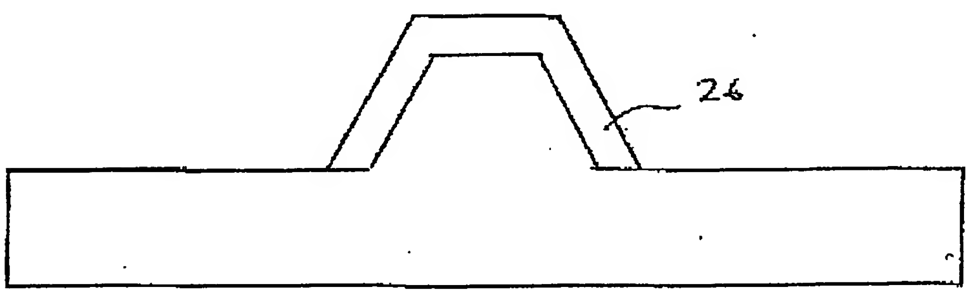

Figure 17b

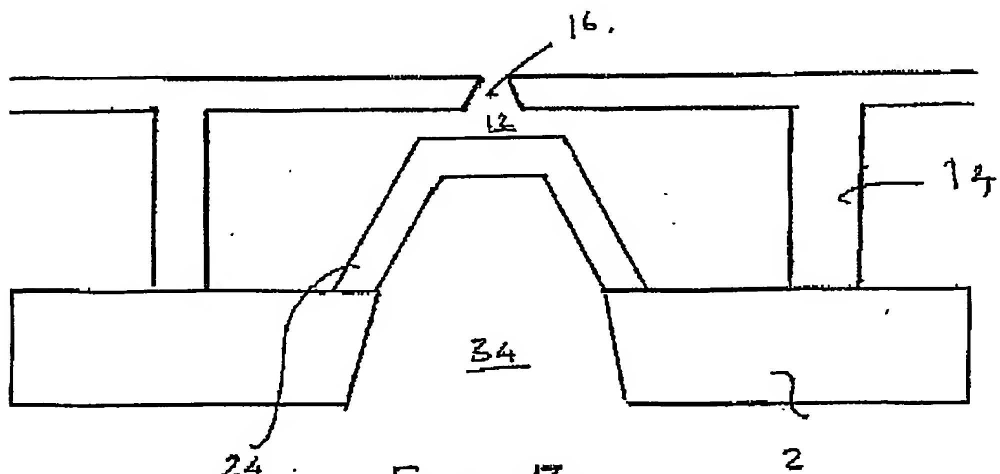

Figure 17c

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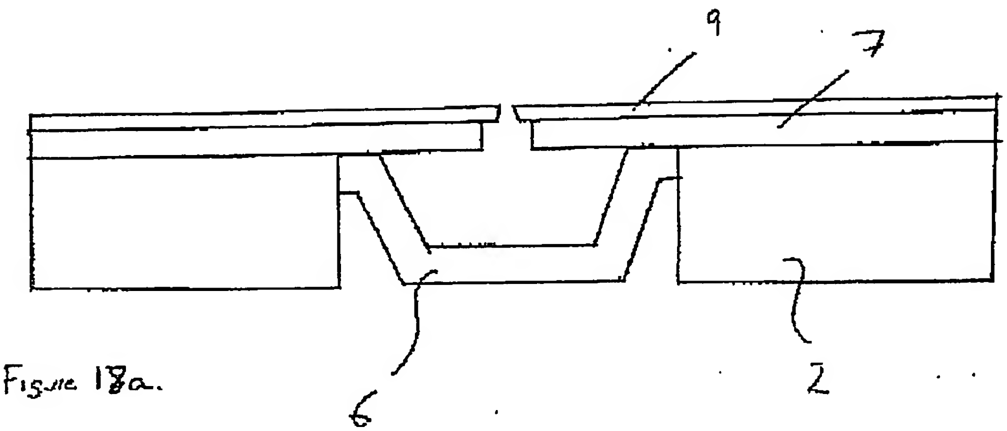

Figure 18a.

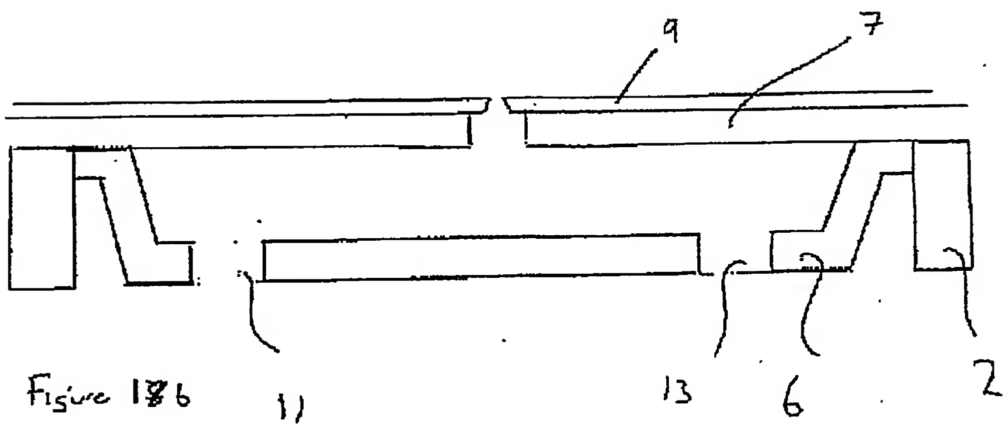

Figure 18b

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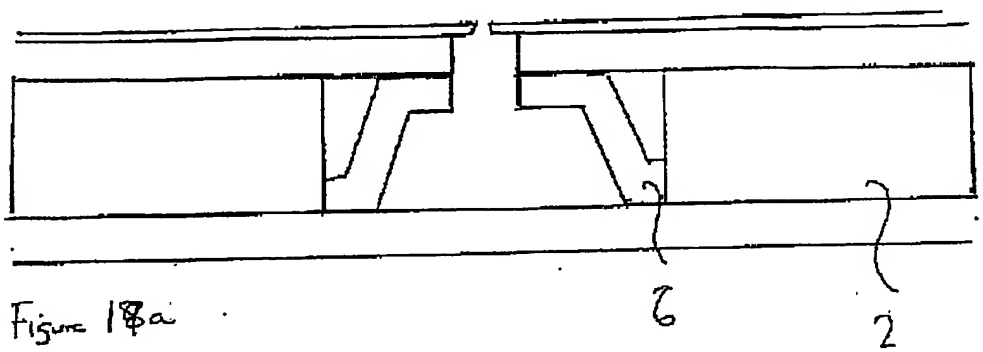

Figure 18a

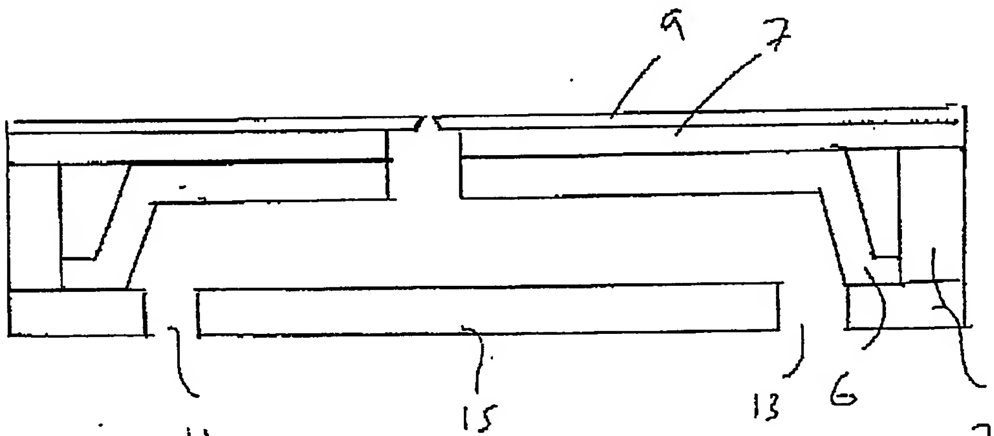

Figure 18b.

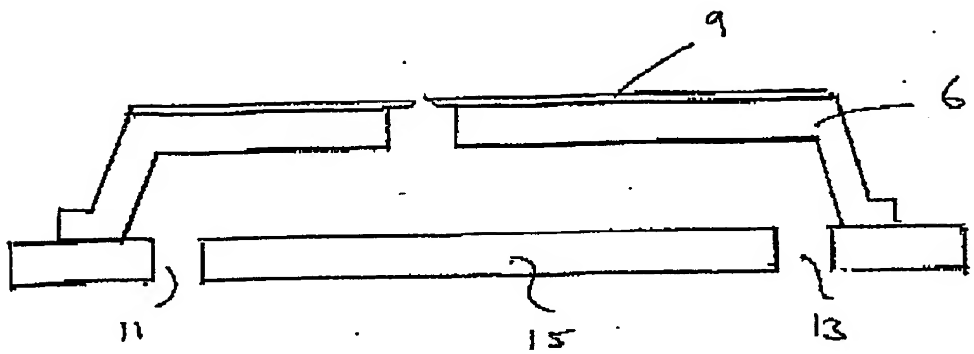

Figure 20